Celanese
The chemistry inside innovation™

Vectra® LCP
Liquid Crystal Polymer (LCP)

Design Guide

List of tables

List of figures

List of figures

1. Introduction and overview

Vectra liquid crystal polymers are a family of highperformance plastics based on patented Celanese technology. They are distinguished from semi-crystalline plastics by their special molecular structure, which consists of rigid, rod-like macromolecules that are ordered in the melt phase to form liquid crystal structures (Fig. 1.1).

The characteristic property profile and behavior of liquid crystal polymers are so different from those of other resins, that LCPs are treated as a separate class of polymer (Table 1.1). Even so, they can be processed by all conventional methods used for thermoplastics, incluing injection molding, extrusion, coextrusion, blow molding, etc.

Fig. 1.1 • Representation of Structural Differences Between Liquid Crystal Polymers and Conventional Semi-Crystalline Polymers

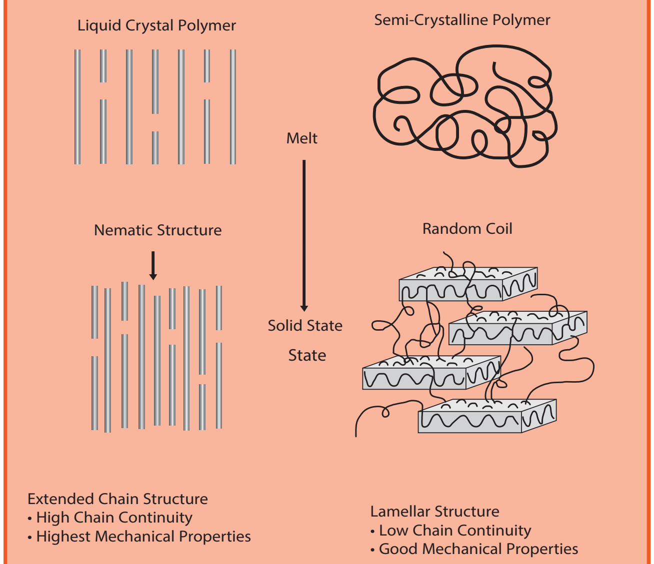


Table 1.1• Comparison of Amorphous, Semi-Crystalline and Liquid Crystalline Polymers

Amorphous Polymers	Semi-Crystalline Polymers	Liquid Crystal Polymers
No sharp melting point/soften gradually	Relatively sharp melting point	Melt over a range of tempera tures; low heat of fusion
Random chain orientation in both solid and melt phase	Ordered arrangement of chains of molecules and regular recurrence of crystalline structure only in solid phase	High chain continuity; extremely ordered molecular structure in both melt phase and solid phase
Do not flow as easily as semi-crystalline polymers in molding process	Flow easily above melting point	Flow extremely well under shear within melting range
Fiberglass and/or mineral reinforcement only slightly improves Deflection Temperature under Load (DTUL)	Reinforcement increases load bearing capab ilities and DTUL considerably, particularly with highly crystalline polymers	Reinforcement reduces anisotropy and increases load bearing capability and DTUL
Can give a transparent part	Part is usually opaque due to the crystal structure of semi-crystalline resin	Part is always opaque due to the crystal structure of liquid crystal resin
Examples: cyclic olefinic copolymer, acrylonitrile-butadiene-styrene (ABS), polystyrene (PS), polycarbonate (PC), polysulfone (PSU), and polyetherimide (PEI)	Examples: polyester (Impet® and Celanex® thermoplastic polyesters, Duranex™ PBT), polyphenylene sulfide (Fortron® PPS), polyamide (Celanese® nylon), polyacetal copolymer (Celcon® POM, Hostaform® POM, Duracon™ POM)	Examples: Vectra® LCP

Vectra liquid crystal polymers offer a balance of properties unmatched by most other resins. They are generally selected for a specific application or market sector based on a few key characteristics such as those shown in Table 1.2 below. For instance, in molding electrical connectors, high flow in thin sections, excellent resistance to heat deflection under load, dimensional accuracy and inherent flame retardancy are the primary reasons for choosing an LCP. Key properties, such as high flow, stiffness and resistance to sterilizing radiation and sterilizing gases make LCPs extremely suitable for use in surgical instruments. A number of Vectra grades are USP Class VIcompliant and meet parts of the ISO 10993 standard (see section 3.5).

The family of Vectra resins are very easy to process in injection molding machines, providing fast cycles, high flow in thin sections and exceptional dimensional stability. Molded parts exhibit very low shrinkage and warpage and have outstanding high-temperature resistance up to 340°C.

Vectra LCPs can be processed into thin films and multi-layer products by conventional methods, although some process adjustments may be required. Films and sheets produced from Vectra have excellent dimensional stability and exceptional barrier properties. Liquid crystal polymers are used in many different sectors, from electronics and medical techno logy to industrial applications.

In addition to the above-mentioned advantages offered by Vectra, other properties such as its low coefficient of linear thermal expansion (CLTE), high chemical resistance, good stiffness, and toughness are observed in many applications.

The performance of the latest Vectra grades goes beyond the requirements for thin-walled precision parts. Attributes such as an attractive surface finish with wide color versatility, good non-stick effect and resistance to cleaning agents make the materials in the Vectra portfolio good candidates for applications that have traditionally been the preserve of metal, such as cookware and bakeware.

Table 1.2 · Key Performance Characteristics by Market Segment

Electrical / electronics
Good flowability in molding thin-walled parts
Dimensional accuracy
Heat resistance
Flame retardancy

Technical fibers
High tenacity fibers with good damping properties
Very good puncture and cut resistance of fibers
Low abrasion
Low moisture absorption

Telecommunications
Good flowability in molding thin-walled parts
Dimensional accuracy
Strength, stiffness

Packaging
Excellent barrier properties
Stiffness
Strength

Automotive industry
Good flowability in molding thin-walled parts
Fuel resistance
Good resistance to low and high temperatures
Low outgassing

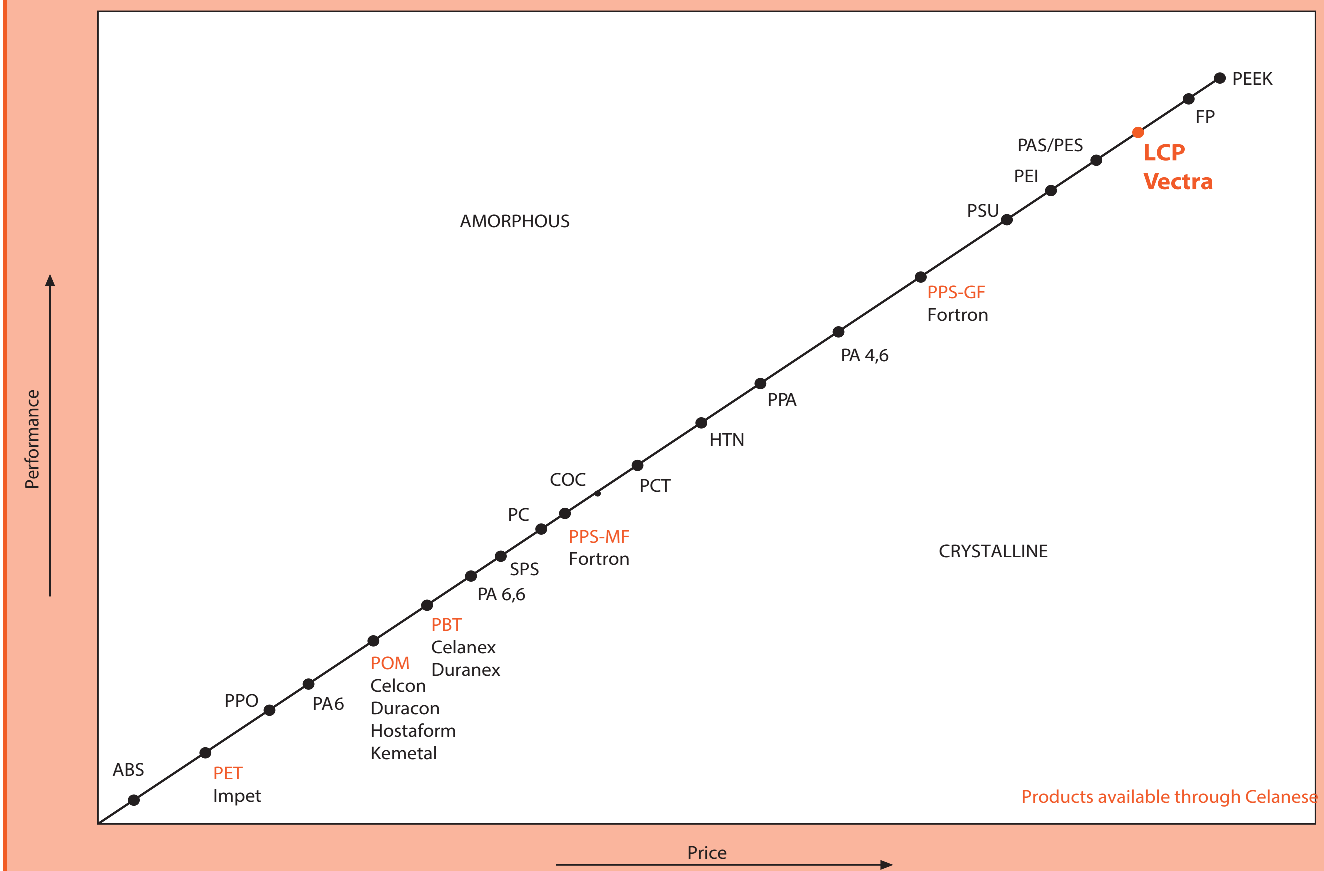
Lighting industry
Good flowability in molding thin-walled parts
Good resistance to low and high temperatures
Low outgassing

Cookware and bakeware
Good non-stick effect
Service temperatures from –196 °C to +280 °C
Stiffness
Low warpage
Dishwasher-safe

Medical technology
Good flowability in molding thin-walled parts
Chemical resistance
Sterilizability
Stiffness, strength

The high strength-to-weight ratio of Vectra LCPs makes them exceptional candidates for metal replacment applications. A maker of needleless medical syringes estimated that injection molded Vectra components were 75% lighter and 50% less costly than operations, so reducing the cost per part. In addition, many Vectra grades are listed by UL as being suitable for use in regrind ratios up to 50% without loss of properties, enabling the processor to improve cost competitiveness even further. Although on a per pound or kilogram basis, Vectra may seem expensive, in an overall cost comparison, it proves to be more cost-effective than other materials (Fig. 1.2). For many applications exposed to high service stresses, Vectra LCPs are the preferred alternative to metal alloys, thermosets and many other thermoplastics.

Fig. 1.2 · Price Performance Comparison of Engineering and High Performance Plastics*



*** High Performance Plastics Acronyms**

ABS = acrylonitrile-butadiene-styrene
COC = cyclic olefin copolymer
FP = fluoropolymers
PA6 = polyamide 6 (nylon)
PA4,6 = polyamide 4,6 (nylon)
PBT = polybutylene terephthalate
PEEK = polyether ether ketone
PES = polyether sulfone
POM = polyoxymethylene (polyacetal)
PPS-MF = polyphenylene sulfide (mineral filled)
PPA = polyphthalamide
SPS = syndiotactic polystyrene
HTN = high temperature polyamide (nylon)
LCP = liquid crystal polymer
PA6,6 = polyamide 6,6 (nylon)
PAS = polyaryl sulfone
PCT = polycyclohexylenedimethylene terephthalate
PEI = polyether imide
PET = polyethylene terephthalate
PPO = modified polyphenylene oxide
PPS-G = polyphenylene sulfide (glass filled)
PSU = polysulfone
PC = polycarbonate

2. Vectra product line

The Vectra product line is built around a number of base polymers with different monomer composition. The base polymers differ in their high-temperature resistance, stiffness, toughness and flow properties. Celanese is continually developing new polymers with properties tailored to the different requirements of specific applications.

Each of these Vectra grades can be used without modification for extrusion or injection molding applications. Care should be taken when using unfilled polymers for injection molding since fibrillation of the oriented surface can occur. As a rule, the base polymers are compounded with various fillers and reinforcing materials to provide the necessary combination of thermal, mechanical, tribological or electrical properties for the specific application or market need. Figure 2.1 surveys the Vectra grades currently available

2.1 Grade descriptions

2.1.1 Glass fiber reinforced grades

Reinforcement with glass fibers increases stiffness, mechanical strength and heat resistance. At the same time, the degree of anisotropy is reduced. Vectra is available with 15%, 30%, 40% or 50% glass fiber content.

Examples:
Vectra A130 (30% glass fibers)
Vectra E130i (30% glass fibers)
Vectra E480i (40% glass fibers)
Vectra S135 (35% glass fibers)
Vectra S150 (50% glass fibers)

2.1.2 Carbon fiber reinforced grades

Reinforcement with carbon fibers gives even higher stiffness than with glass fibers. At the same time, carbon fiber reinforced compounds have a lower density than glass fiber grades with the same filler content. Carbon fiber reinforced polymers are used where the highest possible stiffness is required.

It should also be noted that carbon fiber reinforced grades are to a certain extent electrically conductive.

Examples:
Vectra A230D-3 (30% carbon fibers)
Vectra B230 (30% carbon fibers)

2.1.3 Filler/fiber combinations

Products with various filler/fiber combinations are another important group in the Vectra portfolio. The PTFE and glass modified grades are used for low-friction and wear-resistant applications, while glass/mineral filled products are selected for components requiring both an attractive finish and improved stiffness.

Examples:
Vectra A430 (PTFE)
Vectra A435 FDA (glass fibers, PTFE)

2.1.4 Mineral filled grades

The mineral filled grades typically have high impact strength and elongation at break relative to the glass fiber reinforced grades. In addition, they provide an attractive surface finish and good flow properties. Mineral filled Vectra products are available with 40% filler content.

Examples:
Vectra E540i (40% mineral)
Vectra S540 (40% mineral)

2.1.5 Graphite filled grades

Graphite flake provides some added lubricity and exceptionally good hydrolytic stability and chemical resistance.

Examples:
Vectra A625 (25% graphite)
Vectra S625 (25% graphite)

2.1.6 Specialty grades

Modification with electrically conductive carbon black makes the following products particularly suitable for antistatic applications.

Examples:
Vectra A230D-3 (carbon fibers, conductive carbon black)
Vectra A700 (glass fibers, conductive carbon black)
Vectra A725 (graphite, PTFE, conductive carbon black)

Fig. 2.1 · Vectra® product line

Glass fiber reinforced	A115 A130		E130i E480i E150i	S135 S150
Carbon fiber reinforced	A230D-3	B230		
Fiber/filler modified	A430 A435 FDA		E440i E471i E473i	S471 S475
Mineral filled			E540i	S540
Graphite filled	A625			S625
Electrically conductive	A700 A725			
Electroplatable			E820i E820i Pd E840i LDS	
Alloy	V140		V143XL	
Extrudable (unfilled)	A950			V400P

Vectra base polymers

A polymers – standard polymers best all-round properties

B polymers – highest stiffness

Ei polymers – standard polymers very good flowability SMT solderability

S polymers – highest heat resistance very good flowability SMT solderability

The following grades have been specially developed for electroless plating, EMI/RFI shielding, printed circuit-boards and MID components with integrated circuits.

Examples:
Vectra E820i (mineral)
Vectra E820i Pd (mineral, catalyst)
Vectra E840i LDS (mineral, catalyst)

2.1.7 Medical technology grades

Another product group in the Vectra portfolio comprises medical technology grades tested according to the current standards specified by the medical device and pharmaceutical industries. They are available with different fillers to meet varying application requirements.

Examples:
MT1300 (unfilled)
MT4310 (30% glass fibers)
MT4350 (40% mineral)

2.2 Colors

The natural color of Vectra is beige or ivory. Graphite, carbon black and carbon fiber filled grades are correspondingly black or anthracite in color.

Vectra's high-quality surface finish also provides an opportunity to produce visible parts in attractive colors. The good coloration properties of the material can also be used advantageously to identify or label different components. However, Vectra is not suitable for exact color matching with other materials.

Color masterbatches (or concentrates) with a high pigment loading are available in a wide range of colors (Table 2.1). These masterbatches are supplied as pellets and are added during processing. Color masterbatches based on Vectra "A", "Ei" and S polymers are available and are all cadmium-free.

Table 2.1 · A vailable color masterbatches

A9500 / E9500i		
Color number	**Standard letdown**	**Color**
VD3003K20	20:1	black
VD3003K20	20:1	white
VD3003K20	20:1	blue
VD3003K20	10:1	emerald green
VD3003K20 VD3003K20	10:1 10:1	yellow
VD3003K20	10:1	pink
VD3003K20	10:1	red

For Vectra "A" and "B" grades, color masterbatch Vectra A9500 should be used and for "Ei" grades, color masterbatch E9500i. For Vectra grades based on "S" polymers, only one standard color (S9500 black) is presently available. The Vectra Businessline or Technical Service will be pleased to handle special requests.

The last two digits at the end of the masterbatch code denote the recommended mix ratio of natural pellets to color masterbatch, e.g.:

VJ3040K10 = 10:1 (9 parts pellets: 1 part masterbatch)
VA3031K20 = 20:1 (19 parts pellets: 1 part masterbatch)

Lower concentrations are possible if necessary to achieve the required color effect. Higher concentrations of masterbatch are not recommended because of a potential decrease in material properties and/or flowability at higher loading.

As an alternative to in-house coloration with color masterbatches, it is also possible to obtain Vectra products in melt-colored form, if required. Further information on this can be obtained from the Vectra Businessline or Technical Service.

2.3 Packaging

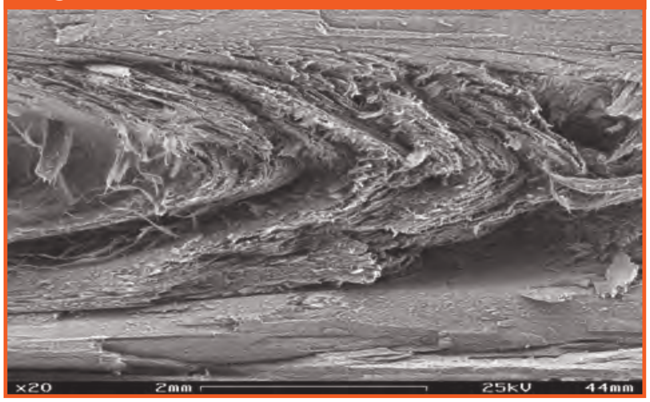
The standard package is a 20/25 kg bag, although other types of packaging, such as gaylords, are available on request.

3. Physical Properties

The physical property values of the individual Vectra grades are shown in the enclosed table.

The properties of Vectra® LCP are influenced to a high degree by its liquid crystal structure. The rod shaped molecules are oriented in the flow direction during injection molding or extrusion and are rod- shaped, even in the melt phase. Due to the highly ordered nature of liquid crystal polymers, mechanical properties, shrinkage and other part characteristics depend on the flow pattern in the part. During mold filling, the molecules are oriented in the flow direction. In the finished part, these molecules are ultimately aligned on the surface where they form a skin that is highly oriented in the flow direction. The skin makes up 15-30% of the part's total thickness (Fig. 3.0). This molecular orientation causes a self-reinforce- ment effect giving exceptional flexural and impact strength as well as good tensile performance. Relative strength values increase as a direct correlation with decrease in wall thickness (see Figures 3.1.3 – 3.1.6).

Fig. 3.0 · Fracture Surface of Unfilled Vectra® LCP



Vectra LCPs belong to the Celanese family of high performance engineering plastics. It is a stiff, tough material with very good flow properties and excellent heat resistance.

A summary of short-term physical properties for the majority of commercially available Vectra grades can be found in the enclosed table. Since the Vectra port- folio is being continually developed, please contact your local customer service for information on the availability of additional grades.

All properties given in the enclosed table were measured on standard injection molded test speci- mens and can be used for grade comparison. Their applicability to finished parts is limited because the strength of a component depends to a large extent on its design. Most physical properties of LCPs depend on processing conditions, so that comparison with data from other sources must always be viewed critically.

The level of properties depends primarily on the type of filler or reinforcement used. Glass fibers impart increased stiffness, tensile strength and heat deflection temperature. Carbon fibers give the highest stiffness. The addition of mineral fillers improves stiffness and provides increased toughness and a smoother surface compared with glass fiber reinforcement. Graphite improves elongation at break and provides added lubricity. PTFE modified grades have excellent sliding and wear properties. The impact strength of unfilled Vectra polymers is reduced by the addition of fillers and reinforcing materials but is still high.

3.1 Mechanical properties

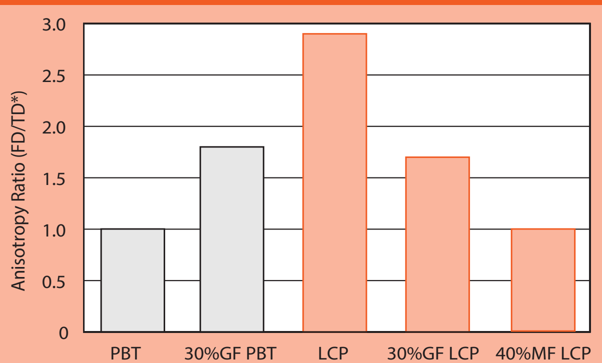
3.1.1 Anisotropy and wall thickness

Liquid crystal polymers are well known to have anisotropic properties when molded into parts. Unlike other engineering polymers, liquid crystal polymers become significantly less anisotropic if formulated with mineral fillers or, to a lesser extent, with glass fiber reinforcement. An example comparing the anisotropy of a Vectra test specimen with that of a test specimen produced from a conventional engineering plastic, PBT, is shown in Figure 3.1.1, both with and without glass fiber reinforcement. The anisotropy of 30% glass fiber reinforced Vectra and 30% glass fiber reinforced PBT is nearly the same. In grades with a high mineral filler loading, the ani- sotropy ratio can even be reduced to 1 (isotropic). It therefore follows that in designing parts molded from glass fiber reinforced Vectra, there is no need to take into account anisotropy-induced changes as compared with the use of other glass fiber plastics. Anisotropic properties can be adequately managed by suitable gate location and wall thickness adjustment.

Table 3.1.1 compares the anisotropy in the flexural and tensile properties of various Vectra grades in sheet form (80 mm x 80 mm x 2 mm). Table 3.1.2 shows the effect of decreasing wall thickness (80 mm x 80 mm x 1 mm) on the anisotropy ratio.

As the wall, film or sheet thickness decreases, the highly oriented outer layer accounts for a higher proportion of the total wall thickness (Fig. 3.1.2). This higher percentage of highly oriented surface

Fig. 3.1.1 • Comparison of Anisotropy* of Vectra® LCP versus Celanex® PBT (ISO universal test specimen)



Tensile strength in flow direction/tensile strength in transverse direction

Table 3.1.1 • Anisotropy of Properties – 2 mm thick

		Unfilled	30% glass filled	30% mineral filled
Flex strength	Ratio FD/TD*	2.7	2.1	2.4
Flex modulus	Ratio FD/TD*	3.6	2.9	3.9
Tensile strength	Ratio FD/TD*	2.3	1.9	2.5
Tensile modulus	Ratio FD/TD*	3.3	2.2	2.7

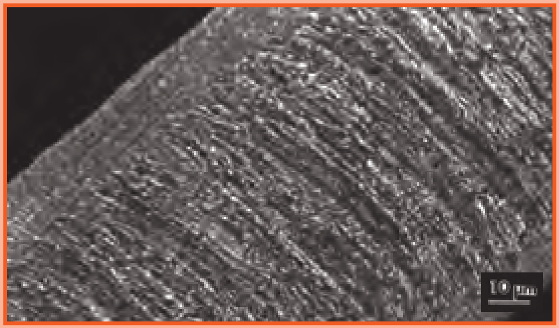
**FD/TD = anisotropy ratio – flow direction/transverse direction*

Table 3.1.2 • Anisotropy of Properties – 1 mm thick

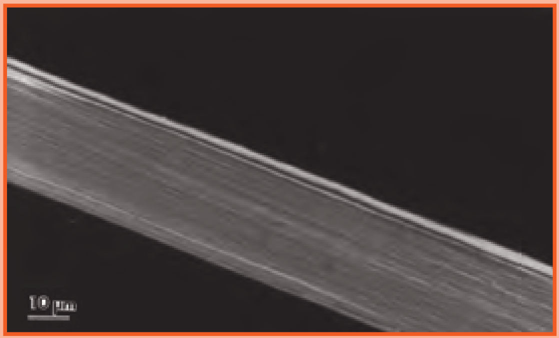
		Unfilled	30% glass filled	30% mineral filled
Flex strength	Ratio FD/TD*	3.9	3.1	2.9
Flex modulus	Ratio FD/TD*	6.7	4.4	4.8
Tensile strength	Ratio FD/TD*	3.6	2.6	3.1
Tensile modulus	Ratio FD/TD*	3.0	2.5	2.8

**FD/TD = anisotropy ratio – flow direction/transverse direction*

Fig 3.1.2 • Micrograph of Fiber Structure showing Orientation of Outer Layers



Strand LCP extrudate shows the higher orientation in the outer "skin" layer but not in the core;



Extruded LCP fiber is highly oriented with all "skin" observed.

Fig. 3.1.3 • Tensile Modulus versus Wall Thickness of Vectra® LCP

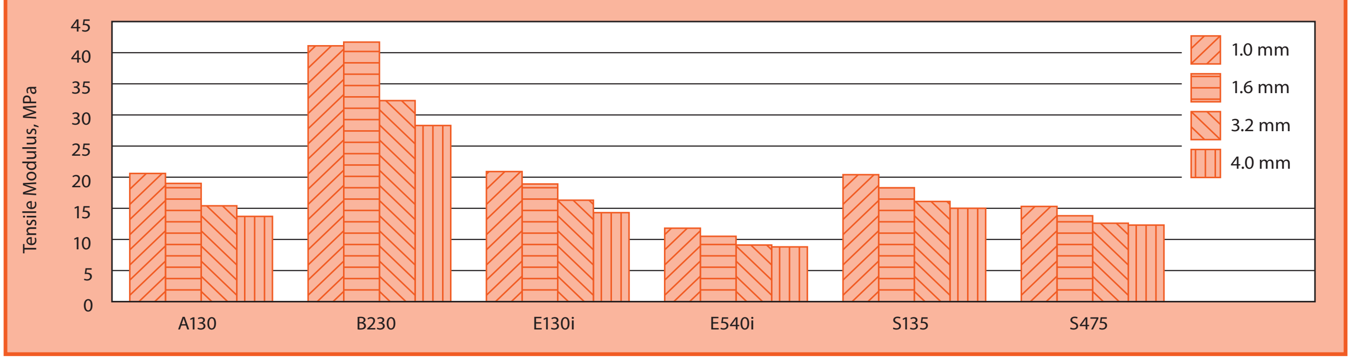


Fig. 3.1.4 • Tensile Strength versus Wall Thickness of Vectra® LCP

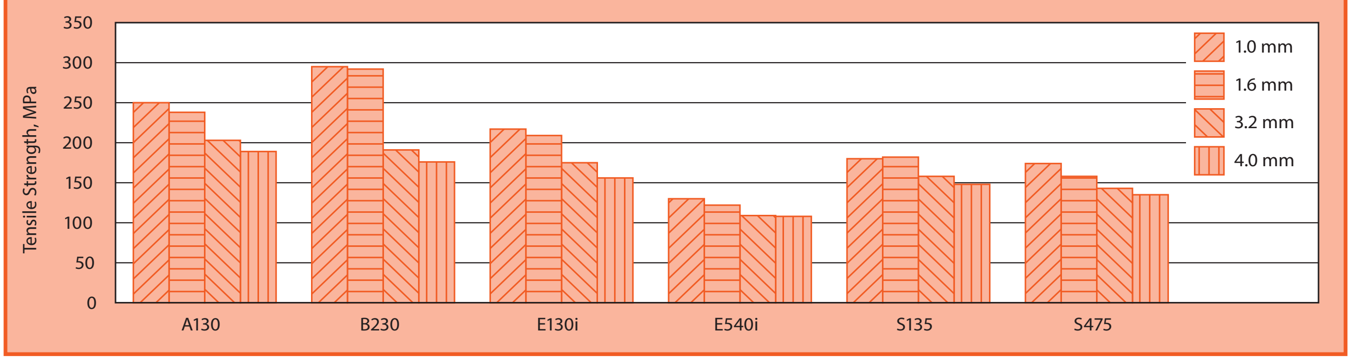


Fig. 3.1.5 • Flexural Modulus versus Wall Thickness of Vectra® LCP

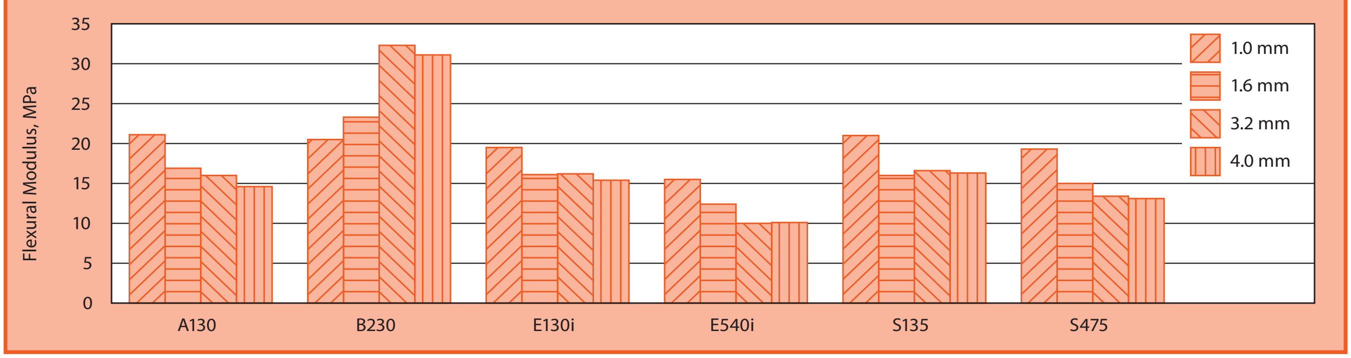
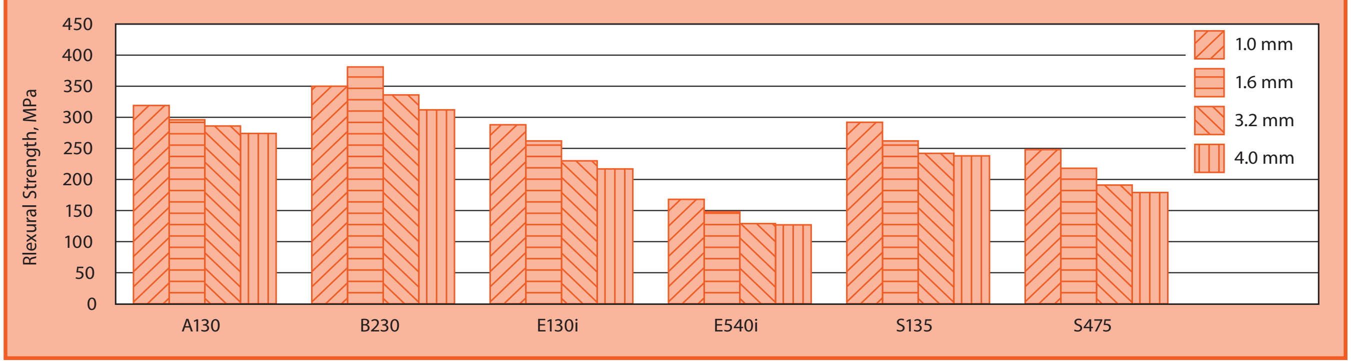


Fig. 3.1.6 • Flexural Strength versus Wall Thickness of Vectra® LCP



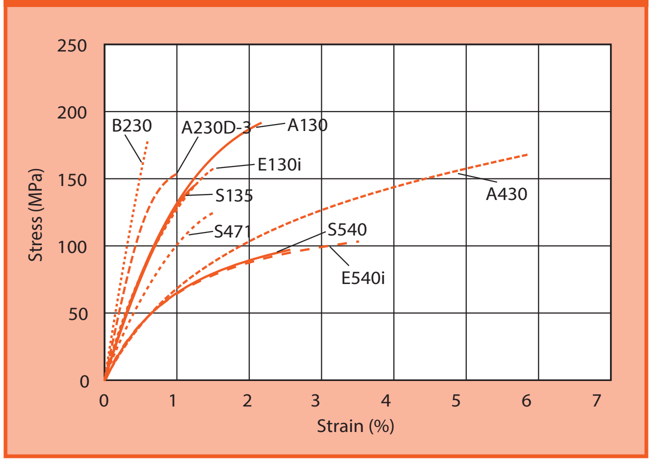
layer, in general, results in greater strength and modulus in thinner sections (Figs 3.1.3, 3.1.4, 3.1.5 and 3.1.6).

The excellent flow properties of Vectra make it possible to fill extremely fine structures and so produce very thin-walled parts.

3.1.2 Behavior under short-term mechanical stress

The tensile stress-strain curves shown in Figure 3.1.7 are representative of the Vectra product line. Vectra A130 and E130i are 30% glass filled resin, S135 is a 35% glass fiber reinforced resins, Vectra A230D-3 and

Fig. 3.1.7 • Stress Strain Curves, Tensile Test at 23°C



B230 are 30% carbon fiber reinforced resins, Vectra A430 is a 25% PTFE filled resin, Vectra E540i and S540 are 40% mineral filled resins, and Vectra S471i is a 45% glass/mineral filled resin.

These products essentially cover the stress-strain range for most filled or reinforced Vectra grades. As with any thermoplastic, the stiffness and strength of the Vectra decreases with increasing temperature. Figs 3.1.8a and b show the influence of temperature on the stress strain curves of Vectra B230 and Vectra E130i. The influence of temperature on tensile properties is given for a number of Vectra grades in Figs 3.1.9 and 3.1.10.

Fig. 3.1.8a • Influence of Temperature on Stress Strain Behavior, Tensile Test, Vectra ® B230

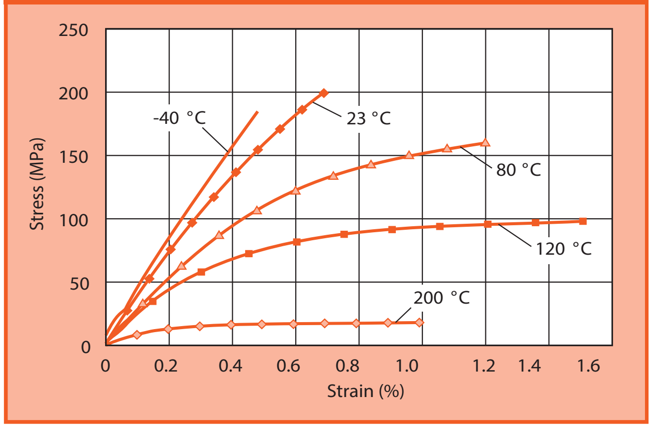


Fig. 3.1.8b • Influence of Temperature on Stress Strain Behavior, Tensile Test, Vectra ® E130i

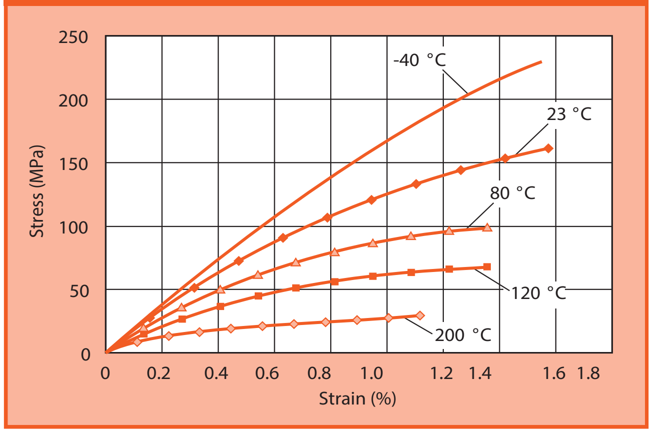


Fig. 3.1.9 • Tensile Modulus versus Temperature, Vectra® LCP

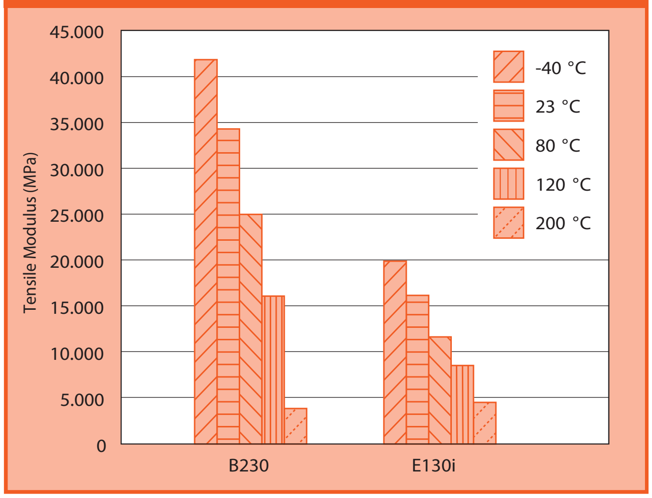


Fig. 3.1.10 • Tensile Strength versus Temperature, Vectra® LCP

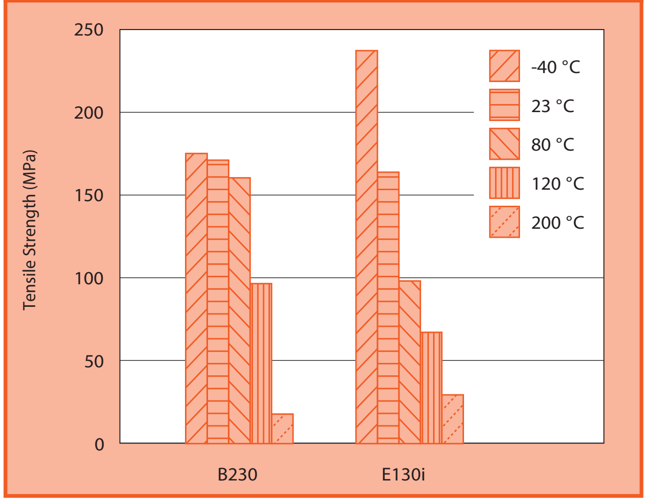
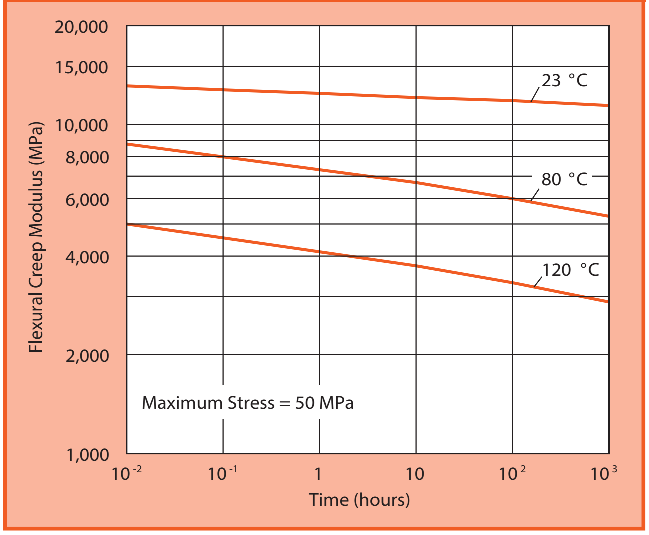


Fig. 3.1.12 • Flexural Creep Modulus, Vectra ® A130

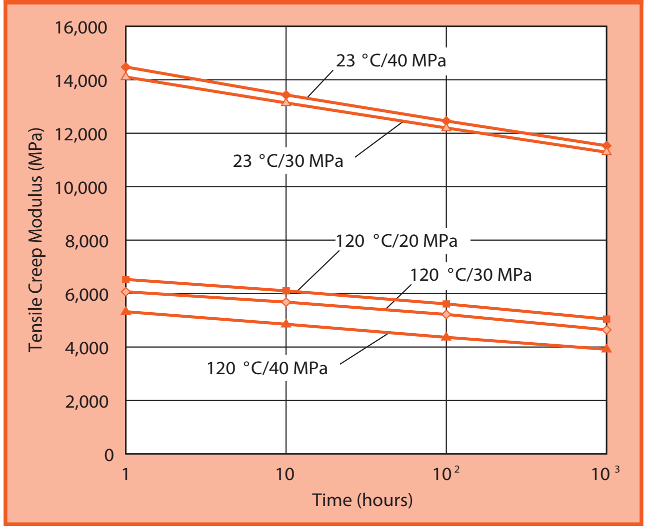


3.1.3 Behavior under long term mechanical stress

Vectra has good creep resistance. Figure 3.1.11 shows the tensile creep modulus of Vectra E130i at 23°C and 120°C for various stress levels. The maximum exposure time was 1000 hours for E130i. The stress levels were chosen to be 30% of the short-term failure stress and none of the samples failed testing. No sign of creep rupture – a common form of failure – was observed at stress levels below 30%.

Fig. 3.1.13 shows the flexural creep modulus of Vectra

Fig. 3.1.11 • Tensile Creep Modulus, Vectra ® E130i



3.1.4 Behavior under impact stress

Vectra grades have very high notched and unnotched Charpy and Izod impact strength because of their wood-like fibrous structure. If this fibrous structure is cut by notching, as in a notched Izod or Charpy specimen, the energy to break is high compared with other glass reinforced plastics.

The values for notched and unnotched impact strength are reported in the enclosed table.

3.1.5 Behavior under cyclic stress

Components subject to periodic stress must be designed on the basis of fatigue strength, i.e. the cyclic stress amplitude σa determined in the fatigue test – at a given mean stress σm – which a test speci- men withstands without failure over a given number of stress cycles, e.g. 107 (Wöhler curve). The various stress ranges in which tests of this nature are con- ducted are shown in Fig. 3.1.16

For most plastics, the fatigue strength after 107 stress cycles is about 20 to 30% of the ultimate tensile strength determined in the tensile test. It decreases with increasing temperature, stress cycle frequency and the presence of stress concentration peaks in notched components.

3

Fig. 3.1.13 • Stress Ranges in Fatigue Tests

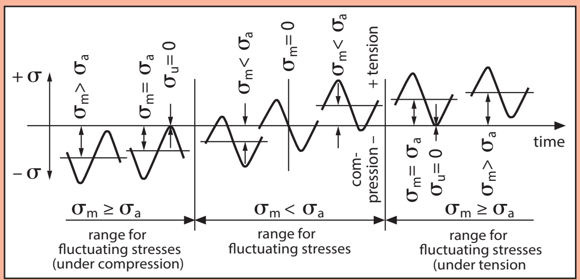
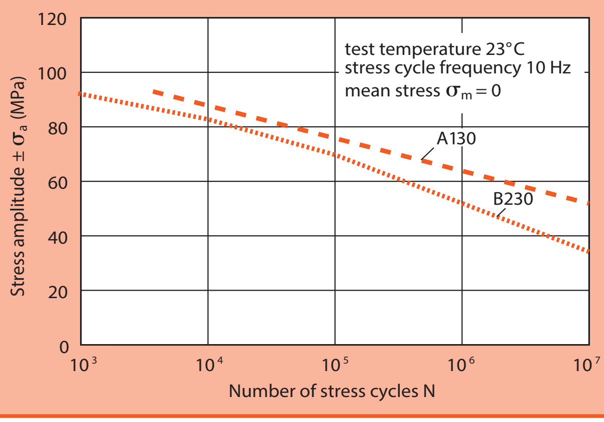


Fig. 3.1.14 • Wöhler Curves for Vectra, longitudinal direction determined in the alternating flexural stress range



The Wöhler flexural fatigue stress curves for various Vectra LCP grades are shown in Fig. 3.1.17. The flexural fatigue strength of Vectra A130 after 107 stress cycles is σ

3.1.6 Tribological properties

The friction and wear characteristics of Vectra are very specific to the application. In general, Vectra resins have good friction and wear properties under low loads. Typical Vectra wear grades contain PTFE, carbon fibers, graphite, or a combination of these with other fillers and reinforcing materials. Dynamic coefficients of friction typically range from 0.1 to 0.2. More specific data can be obtained from standardized tests (Table 3.1.3). However, because friction/slip behavior is dependent on orienta-tion, we recommend testing the finished component under the specific bearing, friction and wear conditions of the applica-tion. bw = 50 N/mm2

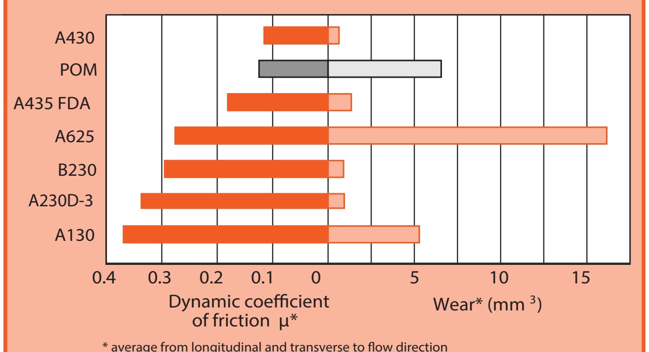
Fig. 3.1.15 compares the dynamic coefficient of friction μ of a number of Vectra grades with that of POM. The test specimens were in unlubricated sliding contact with a rotating steel shaft under low load.

Vectra has moderate surface hardness. Rockwell hardness M values of up to 100 are attained (see the enclosed product information).

Table 3.1.3 • Coefficient of Friction, μ, of Vectra® LCP (ASTM D1894)

Description	Vectra LCP Grade	Coefficient of Friction – Flow Direction	
		Static	Dynamic
Glass Fiber Reinforced	A115	0.11	0.11
	A130	0.14	0.14
Carbon Fiber Reinforced	A230D-3	0.19	0.12
PTFE Modified	A430	0.11	0.11
	A435 FDA	0.16	0.18
Graphite	A625	0.21	0.15
Glass Fiber Reinforced	B230	0.14	0.14

Fig. 3.1.15 • Friction and Wear



Friction: steel ball diameter 13 mm,
load (F_N = 6 N, sliding speed v = 60 cm/min.
Wear: roughness height = 0,1 Ìm,
peripheral speed of the shaft v = 136 m/min,
load (F_N = 3 N, duration of test 60 hr

3.1.7 Damping

The unique structural characteristics of Vectra have an extremely favorable effect on its damping characteristics. Generally speaking, materials with high modulus, such as metals, have low damping (internal loss) characteristics and low modulus materials, such as rubbers, have high damping characteristics. Vectra, however, exhibits high damping characteristics despite its high modulus. This is due to the unique morphology of liquid crystal polymers. The relationship between internal loss, η, and damping factor, l,
is as follows:

$$\lambda T/\pi = \eta$$

where T = cycle and π = 3.14.

Fig. 3.1.16 shows the damping properties of various materials.

Figure 3.1.17 compares the vibration characteristics of different Vectra grades.

Fig. 3.1.16 · Damping Properties

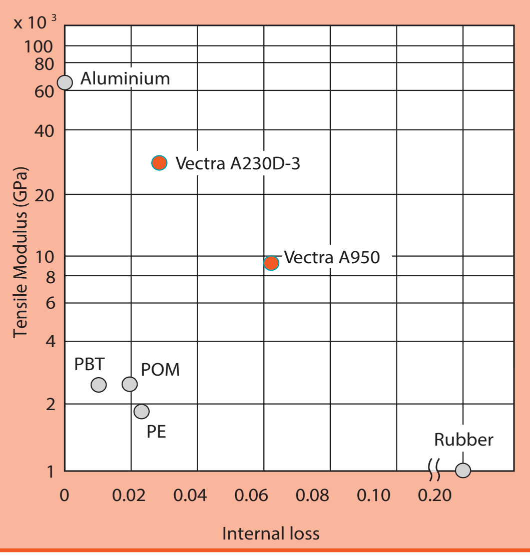
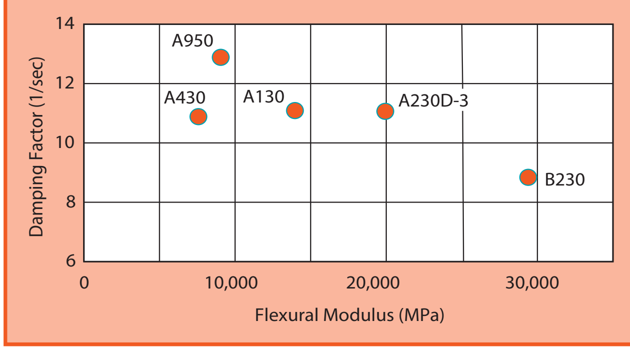


Fig. 3.1.17 · Vibration Characteristics



3

3.2 Thermal properties

3.2.1 Dynamic mechanical analysis (DMA)

A snapshot of the thermomechanical behavior of plastic materials is provided by dynamic mechanical analysis (DMA). This technique is used to determine the storage modulus or stiffness (E′), loss modulus (E′′) and damping or energy dissipation (tan δ) behavior of a material over a wide temperature range. The stiffness or modulus (E′) corresponds to and has nearly the same value as the conventional tensile modulus (E) at temperatures with low loss or damping factor. This modulus represents the recoverable elastic energy stored in a viscoelastic material during deformation. The damping factor (tan δ) represents the energy losses occurring during deformation due to internal molecular friction that occurs in a viscoelastic material.

With this method, the absolute level of the test values depends on the particular test used. Since Vectra® LCP is an anisotropic material, the orientation of the test specimen and direction of mechanical stress have a significant influence on the test values. The results presented here were obtained using the torsion pendulum test. In this method, the test specimen is subjected to a load that is not exactly oriented in the direction of the fiber axes. As a result of the torsional movement, a significant component of the load is applied at an angle to the fiber axes. This reduces the level of the test values and the moduli shown differ from the values obtained in the tensile test.

Table 3.2.1
Dynamic Mechanical Analysis

Sample ID	α transition (T_g) (°C)	β transition (°C)	Modulus E at 23°C (MPa)	Half Modulus Temperature $T_{1/2G}$ (°C)
Vectra A130	97	18	2400	88
Vectra A230D-3	103	21	3200	95
Vectra A430	99	11	1400	83
Vectra A625	98	22	3000	83
Vectra E130i	113	59	2300	119
Vectra E471i	115	57	2500	119
Vectra E540i	117	61	3200	113
Vectra S135	128	35	2400	121
Vectra S471	131	39	3600	119

Fig. 3.2.1 • Dynamic Mechanical Analysis
Vectra® A130

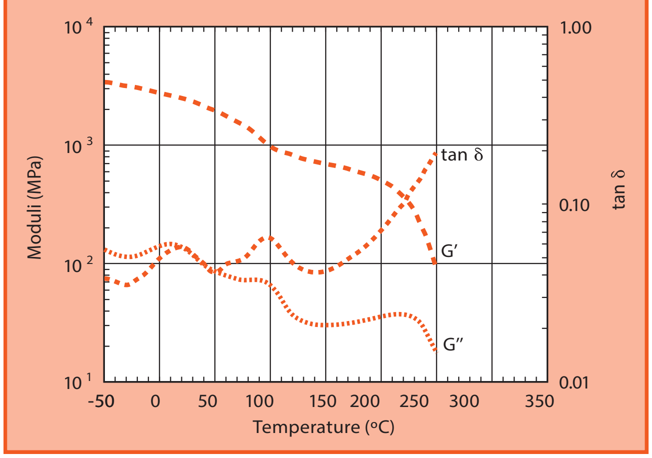


Fig. 3.2.2 • Dynamic Mechanical Analysis
Vectra® E130i

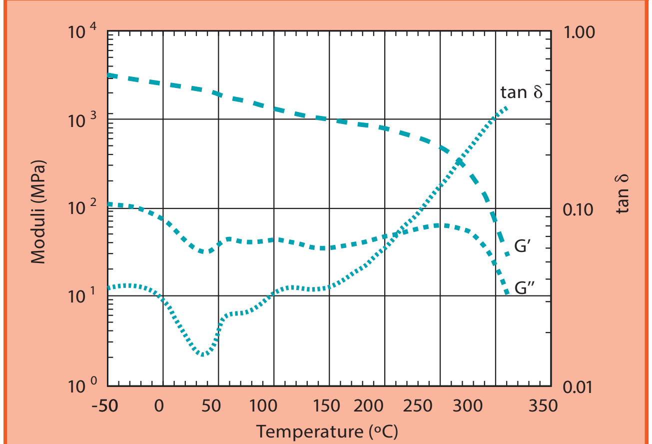
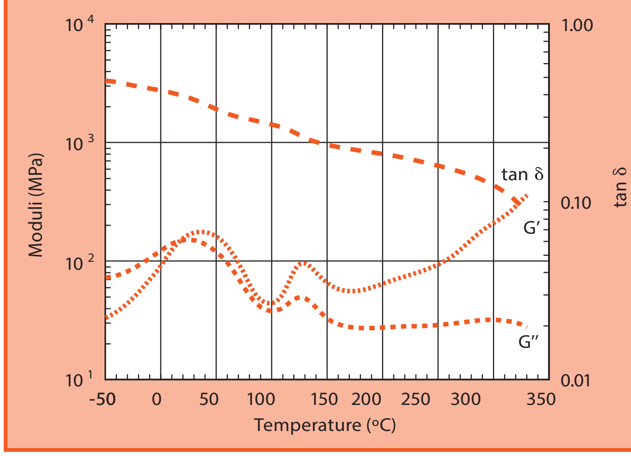


Fig. 3.2.3 • Dynamic Mechanical Analysis
Vectra® S135



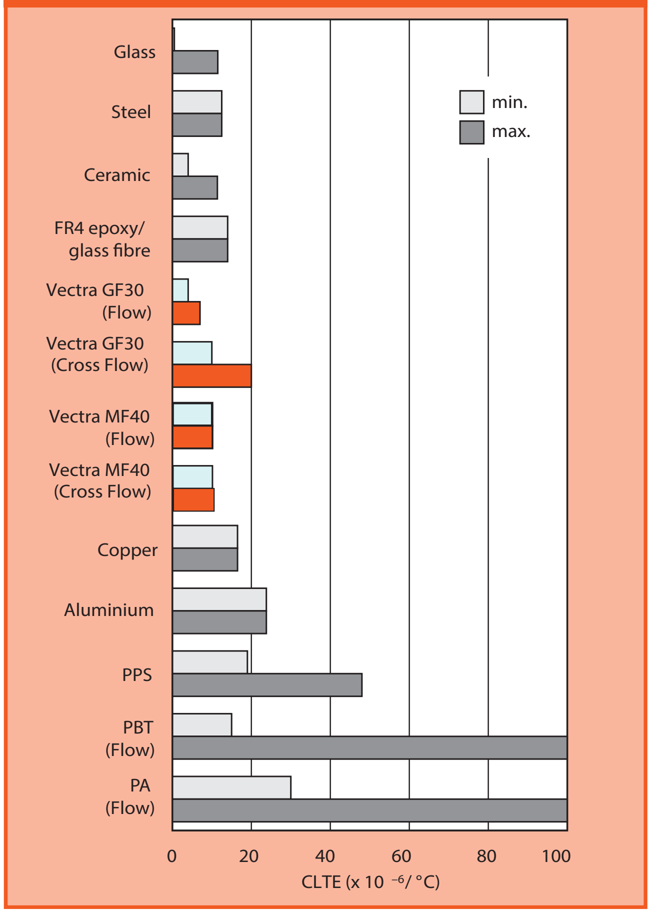
By comparing DMA curves of two or more Vectra polymers (Figs. 3.2.1-3.2.3), retention of stiffness as temperatures are raised is easily compared. Generally speaking, the higher the stiffness at any temperature, the more creep resistant the Vectra grade will be at that temperature. In Table 3.2.1 the temperature at which the modulus falls to 50% of the ambient temperature modulus value is listed for a number of Vectra grades. In general, the higher this temperature, the more creep-resistant the grade will be at elevated temperatures. For example, Vectra A130 (T1/2G = 88ºC) will be more creep-resistant than Vectra A625 (T1/2G = 83ºC) in the temperature range between about 23 to 90ºC. Likewise, Vectra E130i (T1/2G = 119ºC) will be more creep-resistant than Vectra A130 (T1/2G = 88ºC) in the 80 to 120ºC temperature range.

Similarly, peaks in the damping factor curve indicate transitions and temperature ranges where the polymer will be more energy-dissipating (note that the measurement frequencies are very low, of the order of one hertz [cycle/second]. This frequency is well below the audible sound range of 20-20,000 Hz). Typically, Vectra polymers have two strong damping peaks at the glass transition point, α, and the lowtemperature transition point, β. These are listed in Table 3.2.1. Typically, the damping peaks for all Vectra grades fall over a wide range of temperature. Glass transitions are usually in the 120 to 155ºC range with the low temperature secondary loss peaks at 10 to 80ºC. In general, the damping peak temperatures just above ambient make Vectra a good sound absorber. When struck, they do not "ring", but they "clunck" or sound "dead".

3.2.2 Deflection temperature under load

The deflection temperature under load (DTUL/HDT) measured at 1.8 MPa (HDT/A) for Vectra grades ranges from 120°C for an unreinforced, low-temperature product to 340°C for the glass fiber reinforced high heat products. The DTUL values at loads of 8 MPa (HDT/C) and 0.45 MPa (HDT/B) differ considerably from the HDT/A values and are given in the enclosed table.

Fig. 3.2.4 • Coefficients of Linear Thermal Expansion of Selected Engineering Materials



3.2.3 Coefficient of linear thermal expansion

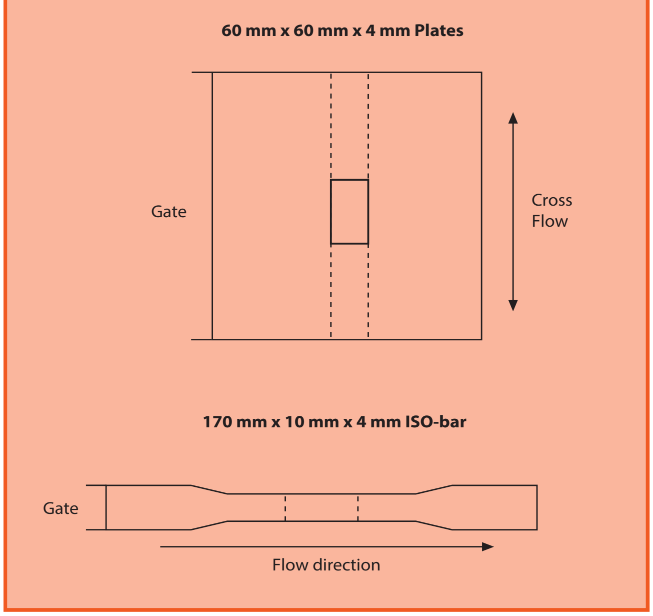
One of the advantages of Vectra is its exceptionally low coefficient of linear thermal expansion (CLTE) in comparison with other thermoplastics. The expansion coefficient change only slightly and almost linearly. The coefficient of expansion, like most properties of Vectra, displays marked anisotropy. It is much lower in the flow direction than the cross-flow direction. With very high orientation in the flow direction, the expansion coefficient may even be negative, especially for carbon fiber reinforced grades.

The expansion coefficient of Vectra can be varied within certain limits and matched to the expansion coefficient of glass, steel, ceramic, or glass fiber/ epoxy substrates. Fig. 3.2.4 compares the expansion coefficients of various engineering materials. When composite structures of Vectra and other materials are heated, no thermally induced stresses occur because the thermal expansion coefficients are similar. Electrical components for surface mounting (SMD or surface mounted devices) should have expansion coefficients closely in line with those of the circuit board substrate (usually FR 4 epoxy plastic/glass fiber) to avoid mechanical stresses at the soldering points as a result of thermal loading. Vectra is therefore a good material for composite structures, particularly for surface mount technology (SMT). The expansion coefficient depends on the flow pattern and therefore on fiber orientation in the part.

Table 3.2.2 • Coefficient of Linear Thermal Expansion (–50°C to 200°C)

	Coefficient of Linear Thermal Expansion ($x\,10^{-6}$/°C) 30 x 10 x 4 mm cut out from ISO Test Specimens	
Vectra	**Flow**	**Cross Flow**
A130	5	20
B230	1	8
E130i	5	19
E540i	11	12
E471i	4	15
S135	4	22

Fig. 3.2.5 • Sample Geometry for CLTE Measurements



The more uniform the filling pattern in injection molding a given section of the part, the lower the anisotropy of the thermal expansion coefficient in the various spatial directions. The higher flow-induced orientation in the ISO test specimen is reflected in the higher anisotropy of the linear expansion coefficient. With the more balanced flow and orientation properties of the 60 x 60 x 4 mm test plaque, the expansion values are also more balanced (see Figure 3.2.10). The two values measured on this test plaque effec tively represent the achievable spectrum of the thermal expansion coefficient. The thermal expansion coefficients of selected grades are compared in Table 3.2.3 and further data can be obtained from the enclosed table and the technical data sheets.

3.2.4 Soldering resistance

Parts molded from Vectra LCPs are suitable for applications requiring vapor phase (wave) and infrared (reflow / SMD / through-hole) soldering. They are dimensionally stable and have extremely low thermal expansion coefficients at soldering temperatures. Vectra LCPs exceptionally low moisture absorption has a positive effect on dimensional stability, minimizing dimensional changes and warpage.

Table 3.2.3 • Vapor Phase Soldering Stability of Vectra® LCP

		Change in Dimensions after Immersion in Fluorinert FC70 at 215°C (%)	
		45 s immersion	**120 s immersion**
Vectra A130 (30% GF)	ΔL	0.05	0.05
	ΔW	0.05	0.05
	ΔD	0.05	0.05
PBT (30% GF)	ΔL	0.2	0.22
	ΔW	0.3	0.5
	ΔD	0.2	0.32
PPS (40% GF)	ΔL	0.15	0.16
	ΔW	0.53	0.55
	ΔD	0.55	0.57

GF = fiber glass reinforced
ΔL = change in length dimension (%)
ΔW = change in width dimension (%)
ΔD = change in depth dimension (%)

Table 3.2.4 • Soldering Compatibility of Vectra® LCP

Solder Bath Temperature (°C)	Dipping Time (s)	Vectra A130	Vectra E130i	Vectra S135
240	10	O	O	O
	60	O	O	O
260	15	O	O	O
	20	Δ	O	O
	45	Δ	O	O
	60	Δ	O	O
280	10	--	O	O
	30	--	O	O
	45	--	Δ	O
	60	--	Δ	O
	90	--	--	O
290	60	--	--	O
300	30	--	--	O
310	10	--	--	O
	15	--	--	O

O = no change in appearance *-- = not tested*
Δ = change in appearance

Table 3.2.3 shows dimensional changes in a 56 mm long connector with 40 contacts after immersion in Fluorinert FC70, which is used in Vapor Phase Soldering.

Resistance to soldering temperatures of a number of Vectra grades is given in Table 3.2.4. Experience has shown that Vectra A130 is resistant to soldering temperatures up to 240°C. Above this temperature, parts can soften or distort due to the proximity of the melting point (280°C). Vectra E130i, with its much higher melting point (335°C), is able to withstand short-term soldering temperatures of up to 300°C. The introduction of high-temperature grades such as Vectra S135 (melting point 350°C) significantly extends the possible processing window.

The melting point is, however, only one criterion for assessing the suitability of Vectra grades for exposure to soldering operations. Another important consideration is heat deflection temperature under load. It is necessary to decide on a case by case basis whether to use HDT/A or resistance to other loads such as HDT/B or C as the basis. In making this decision, loads due to internal pressure in the component (e.g. from trapped inert gas) or other mechanical effects, such as clamps, must be taken into account.

As a result of the increased use of lead-free soldering, temperature peaks in the soldering operation have risen to 270°C. It should be noted that Vectra Ei and S grades are suitable for such soldering operations, provided that they have been correctly processed.

Frequent faults include insufficient drying of the material before processing or excessive shearing of the material. Mineral filled grades may in some cases require more careful drying than glass fiber reinforced grades. Shear is introduced by the screw on the injection molding machine and in the mold during the injection phase. Poor processing is usually indicated by blistering on the component surface during the soldering operation. Here we would refer you to the troubleshooting recommendations in section 6.4.

3.2.5 Thermodynamics, heat of fusion

Figure 3.2.6 shows the specific heat Cp of Vectra LCPs as a function of temperature compared to PPS and PBT. Vectra LCPs have a significantly lower specific heat than semi-crystalline thermoplastics. The curves are more like those for amorphous thermoplastics. This is attributed to the liquid crystalline structure of Vectra. With LCPs, the transition from the solid to the melt phase is associated with a relatively small change in the state of order since the melt maintains the high orientation of the solid.

Because of the high order of the melt state and the ability to solidify with minimal change in structure, the transition energy during melting or freezing of

Fig. 3.2.6 · Specific Heat

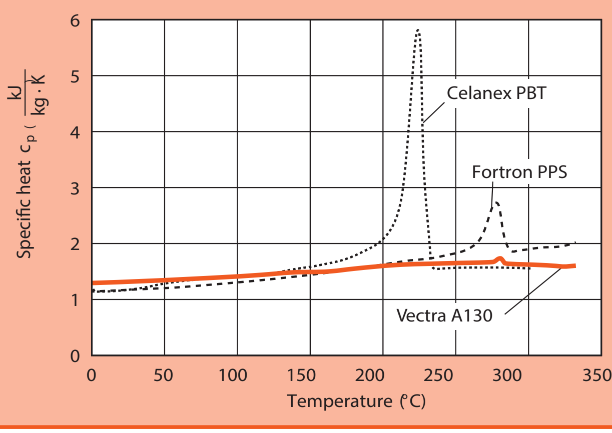


Fig. 3.2.7 · Relative Phase Transition Energy

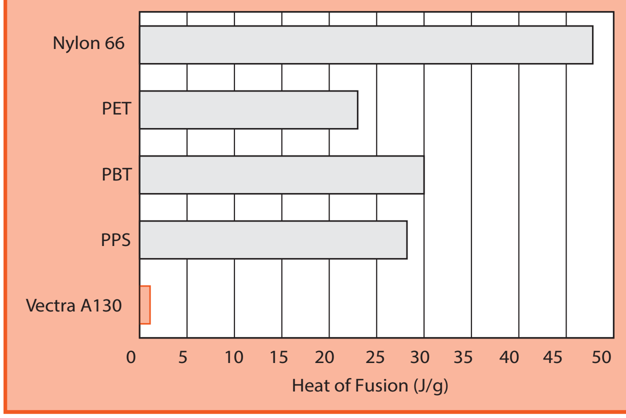
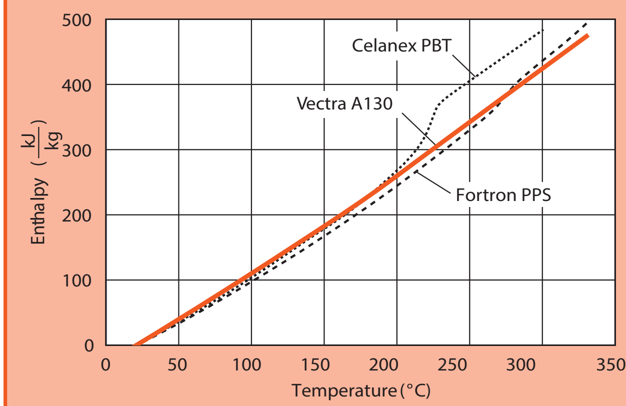


Fig. 3.2.8 · Enthalpy



3

Vectra is one to two orders of magnitude less than that of semi-crystalline thermoplastics (Fig. 3.2.7).

Figure 3.2.8 shows the relative phase transition energies of Vectra A130, Celanex PBT and Fortron PPS throughout the heating or cooling cycle.

In designing the optimum of injection molding machinery and parts, it is essential to know how much heat must be supplied or removed during processing. With Vectra, less heat has to be removed and the melt freezes rapidly. This means that much faster cycles are possible than with semi-crystalline materials, so thus permitting lower-cost production of parts. The thermal conductivity λ of unreinforced Vectra is in the same range as that for semi-crystalline polymers. Thermal conductivity is dependent both on the base polymer and the type as well as the use of fillers and reinforcements (Fig. 3.2.9).

3.2.6 Outgassing behavior

Vectra LCPs have very good outgassing behavior compared with other high-temperature thermoplastics Vectra moldings that are exposed to high temperatures in either the short or long term leave little or no deposits on adjacent cooler surfaces.

Emissions are generated by low-molecular-weight raw material residues or decomposition products. However, the reaction process used in Vectra LCPs manufacturing ensures reliable reaction of the raw materials, while the heat resistance of the polymer minimizes thermal degradation. In addition, the small fraction of low-molecular-weight residues has such a low boiling point that as a rule it does not cause deposits on contacts, diffusors or lenses adjacent to heat-stressed Vectra components.

The emission level for standard grades is below 500 ppm at a temperature of 250°C over 5 hours (Fig. 3.2.10). Through the use of high-temperature Vectra grades, this value can be reduced to below 50 ppm under the same conditions.
Thermal

Fig. 3.2.9 • Thermal Conductivity

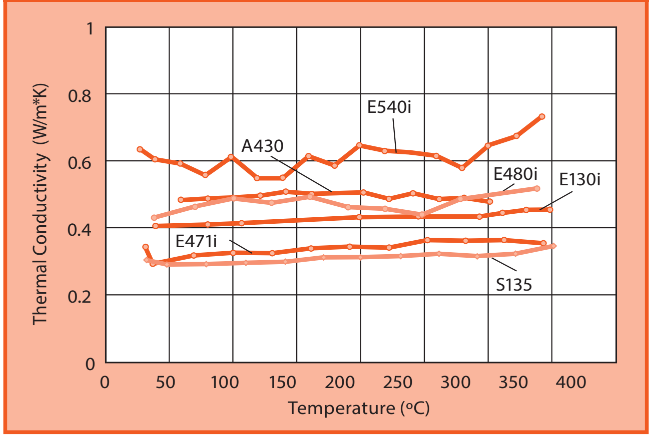
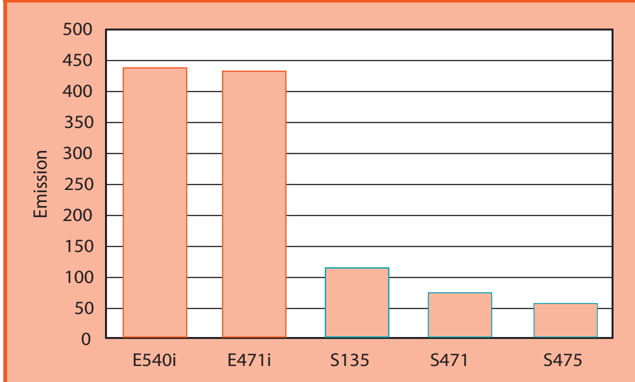


Fig. 3.2.10 • Outgassing* of Vectra® LCP



* *measured at 250 °C / 20h*

3.3 Behavior on exposure to flame

Vectra LCPs are inherently flame retardant and selfextinguishing. On exposure to very high flame temperatures, the fully aromatic Vectra polymers form a carbon char layer, which retards the development of flammable gases.

Vectra LCPs have a self ignition temperature of over >540°C. The onset of thermal degradation in air is not significant until temperatures of over 380°C are exceeded.

The Limiting Oxygen Index (LOI) according to ASTM D 2863-77 represents the minimum amount of oxygen as a percentage in air at which the combustion of the polymer will continue after ignition without an additional source of energy. The LOI of Vectra ranges from 40% to 50% depending on the base polymer.

Smoke density measurements and combustion products for a representative grade, Vectra A950, are given in Tables 3.3.1 and 3.3.2. The main combustion products are carbon dioxide, carbon monoxide and water. Vectra LCPs also achieved very good results in the Ohio State University (OSU) heat release test (Table 3.3.3).

Vectra conforms to Underwriters Laboratories UL 94 V-0 at thicknesses as low as 0.2 mm with some grades. The UL listings can be reviewed at Under - writers Laboratories under file number E83005.

Please note that Celanese is continually developing new grades of Vectra or adding to the data already available for current grades. Please contact the Celanese technical service team or log on to www.Celaneseus. com (Product Information/Agency Compliance) for the most up-to-date UL information.

3.4 Electrical properties

Vectra LCPs exhibit good electrical properties (see enclosed product information). The electrical characteristics combined with easy processing, dimensional stability, heat reisstance and mechanical integrity make Vectra LCPs a good choice for electronic components, especially surface mounted devices (SMD). Vectra grades are also available with low to moderate electrical conductivity (Table 3.4.1).

Table 3.3.1 • Smoke Density of Vectra® A950 (National Bureau of Standards Smoke Density Chamber, ASTM E-662)

	Thickness			
	1.6 mm		3.2 mm	
	Flaming	Smoldering	Flaming	Smoldering
Specific smoke density after 1.5 minutes	–	–	–	–
Specific smoke density after 4.0 minutes	7	–	3	–
Maximum value for specific smoke density	95	2	94	1
Time to smoke density of 90% of maximum value (minutes)	17	20	17	19

Table 3.3.2 • Products of Combustion (in ppm) of Vectra® A950 (National Bureau of Standards Smoke Density Chamber, ASTM E-662, Generated on 3.2 x 76.2 x 76.2 mm plaques)

	Thickness			
	1.6 mm		3.2 mm	
	Flaming	Smoldering	Flaming	Smoldering
Chlorine	–	–	–	–
Phosgene	–	–	–	–
Hydrogen chloride	–	–	–	–
Hydrogen fluoride	–	–	–	–
Formaldehyde	–	–	–	–
Ammonia	–	–	–	–
Carbon monoxide	320	<10	300	<10
Carbon dioxide	8000	600	7000	600
Nitrogen oxides	5	–	12	–
Hydrogen cyanide	–	–	–	–
Sulfur dioxide	–	–	–	–
Hydrocarbons as n-octane	250	–	300	–

Table 3.3.3 • Heat Release of Vectra® A950 (Ohio State University)

Thickness of test plaque	Accumulative heat release after 2 minutes (kW min/m²)	Maximum rate of heat release (kW/m²)
1.6 mm	16.8	57.8 (after 177 seconds)
3.2 mm	2.4	59.2 (after 293 seconds)
Specification (FAR)	<65	<65

Meets U.S. Federal Air Regulation, FAR25.853 (A-1), part IV, appendix F governing materials used in aircraft

3

Tab. 3.4.1 • Vectra® LCP Conductive Grades

	Vectra A230D-3 Carbon fiber	Vectra A700 Carbon black	Vectra A725 Graphite/ carbon black
Volume Resistivity* (Ω · m)	10^0	10^3	10^1
Surface Resistivity (Ω)	10^1	10^5	10^4

** Measured on molded plaques painted with conductive silver*

Tab. 3.4.2 • Electrical Properties of As-Molded/Un-Plated Vectra® LCP

	1 MHz	10 MHz	100 MHz	1 GHz	2 GHz
Relative Permittivity					
A130	3.7	3.2	3.5	3.2	–
A430	3.1	2.8	–	–	–
E130i	3.3	3.2	3.2	3.1	–
E471i	3.8	3.7	–	–	–
E820i	3.6	–	–	–	–
S135	3.5	3.4	–	–	–
Dielectric Loss Tangent					
A130	0.018	0.008	0.007	0.006	–
A430	0.016	0.008	–	–	–
E130i	0.025	0.02	0.01	0.008	–
E471i	0.031	0.007	–	–	–
E820i	0.03	–	–	–	–
S135	0.009	0.023	–	–	–

Tab. 3.4.3 • Electrical Properties of Gold Plated Vectra® LCP

	1 MHz	10 MHz	100 MHz	1 GHz	1,8 GHz
Relative Permittivity					
A130	5.18	5.05	5.00	5.01	5.00
A430	4.34	4.25	4.20	4.19	4.23
E130i	6.77	6.49	6.33	6.26	6.29
E820i	7.19	6.92	6.79	6.74	6.79
E820i Pd	6.79	6.54	6.42	6.39	6.43
Dielectric Loss Tangent					
A130	0.014	0.009	0.006	0.006	0.006
A430	0.009	0.006	0.003	0.004	0.005
E130i	0.019	0.015	0.010	0.004	0.004
E820i	0.016	0.014	0.009	0.004	0.006
E820i Pd	0.016	0.013	0.008	0.003	0.005

These products are good candidates for antistatic applications and electromagnetic shielding (EMI).

There has so far been no common industry standard for determining the dielectric properties of materials. Several test methods were therefore evaluated. In the method finally selected (IEC 250), round test specimens with a diameter of 10 mm were punched out of 0.4 mm thick injection molded plaques and then metallized on both sides by gold vapor deposition. The plating helps eliminate possible fault sources such as surface unevennesses. A rough surface tends to lead to lower relative permittivity (DC) values and higher dissipation factors (tan δ) due to poor contact. The relative permittivity values determined by the method used here therefore tend to be relatively higher and the tan δ values lower than values measured on unplated specimens (see enclosed table). On the other hand, they are more realistic, since antennae or parts for shielding applications are normally also metallized. When selecting materials on the basis of relative permittivity (DC) and tan δ values, it is therefore essential to take into account the specific test method used to determine the dielectric characteristics.

Tables 3.4.2 and 3.4.3 give the relative permittivity values and dissipation factors at various frequencies for some selected Vectra grades used in antennae and shielding applications.

Figure 3.4.2 shows the relativity permittivity and dissipation factors of some characteristic Vectra grades as a function of frequency. The temperature dependency of these values can be seen in Figure 3.4.1 for the E820i Pd grade specially developed for plating.

The tests were carried out by COMTECH Labor für Kunststoffe GmbH Munich on a Hewlett Packard HP 4291A RF impedance analyzer in the 1 MHz to 1.8 GHz range. Underwriters Laboratories (UL) has evaluated the majority of Vectra grades. They report measurements of flammability, arc resistance, hot wire ignition, high current arc ignition, high voltage tracking rates and comparative tracking index. The data is reported on the UL "yellow card". Many Vectra products allow the use of 50% regrind while continuing to maintain the UL rating.

Fig. 3.4.1 · Relative Permittivity/Dielectric Loss Tangent vs Temperature, Vectra® E820iPd, Gold Plated

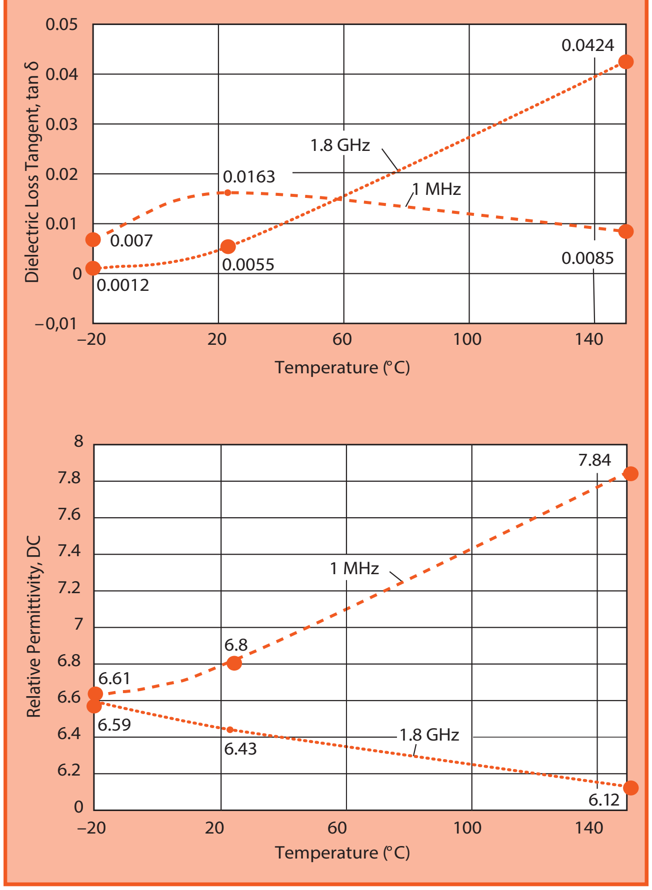
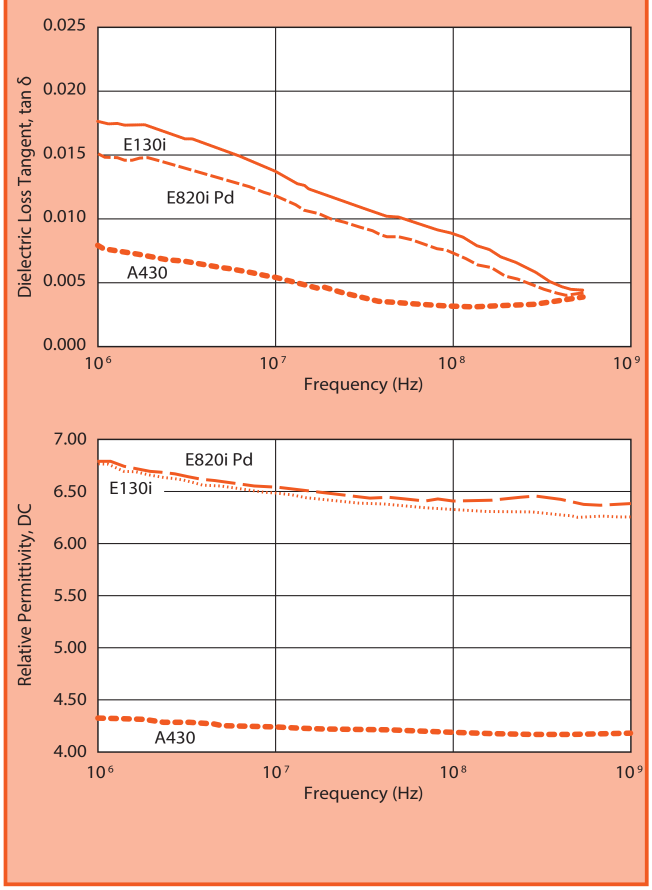


Fig. 3.4.2 · Relative Permittivity/Dielectric Loss Tangent vs Frequency for Vectra®, Gold Plated

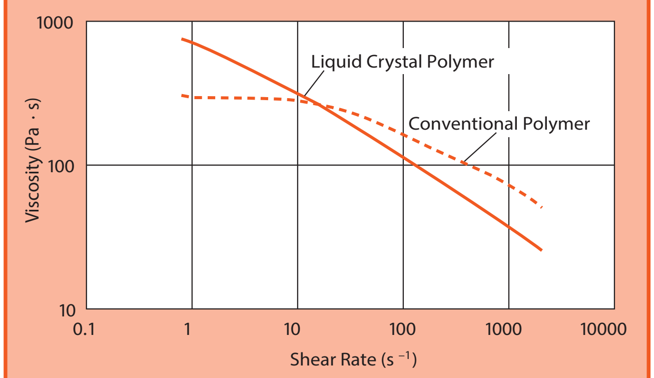


In addition, the UL tests also establishes the RTI (= relative thermal index). Based on thermal agin measurements, the RTI for a given formulation gives a guideline temperature for the long-term retention of characteristic properties such as dielectric strength, tensile strength (mechanical strength without impact) and tensile impact strength. Vectra products are assigned a generic RTI rating of 130°C based on their chemistry and historic performance, before testing is complete.

3.5 Rheological properties

Vectra® LCPs have a nematic liquid crystal structure. The melt viscosity decreases continually with in -creasing deformation (shear) rate. At the shear rates that normally occur during injection molding, the melt viscosity of Vectra is lower than that of conventional filled or reinforced polymers (Fig. 3.5.1).

Fig. 3.5.1 • Melt Viscosity Comparison Vectra® LCP versus Semi-Crystalline Polymer



The melt viscosity values of some important glass filled grades as a function of temperature are compared in Fig. 3.5.2.

The melt viscosity values for selected unfilled Vectra polymers frequently processed by extrusion are shown in Fig. 3.5.3.

With Vectra LCPs, it is possible to fill very thin walls down to less than 0.2 mm. The injection pressures are lower than with amorphous or semi crystalline resins. Vectra can be used to produce thin-walled miniature parts and complicated parts with long flow paths, such as long, narrow connectors or small coil bobbins. Despite good melt flow at the high shear rates, which normally occur in injection molding, Vectra does not form any flash. It is therefore possible to mold thinwalled articles and parts with movable cores without any flash. In the case of connectors and relays, for example, this can sometimes bring a considerable reduction in manufacturing cost because, the costly deflashing step is unnecessary.

Fig. 3.5.2 • Melt Viscosity versus Temperature (Glass filled grades at shear rate = 1.000/s)

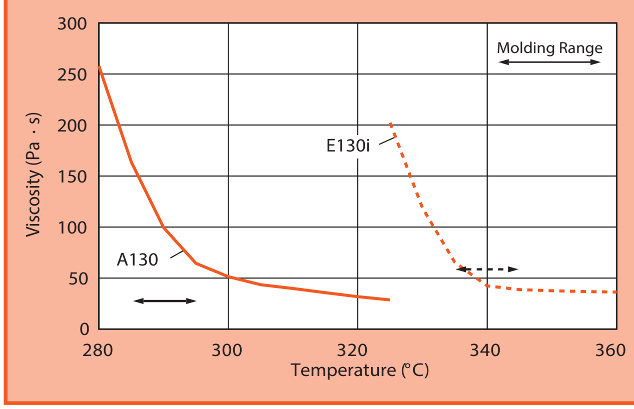
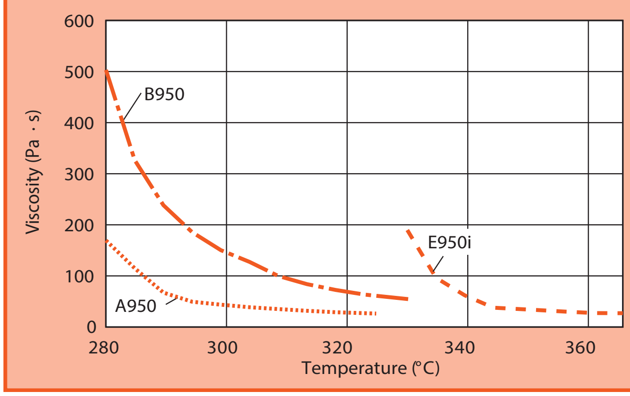


Fig. 3.5.3 • Melt Viscosity versus Temperature (Unfilled grades at shear rate = 1.000/s)



3.6 Regulatory approvals and standards

3.6.1 Food contact / materials and articles

EU:

For plastics to obtain food contact approval, the raw materials used must be listed under the German Regulations for Materials and Articles Coming into Contact with Food (BG-VO) or other national regulations, such as the Recommendations of the German Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung – BfR, previously the BgVV and, before that, the BGA). The BG-VO regulations transpose into German national law the EU Directive 2002/72/EC ("Plastics Directive") and its 4 amendments 2004/1/EC, 2004/19/EC, 2005/79/EC, and 2007/19/EC.

If limits are specified for the listed substances, then the finished parts must be tested by the manufacturer or seller to ensure compliance. If the plastic consists of listed substances that are not subject to any individual limit, then the finished part must be tested for global migration.

Most of the raw materials used to produce our Vectra grades are listed in EU Directive 2002/72/EC (and the BG-VO), i.e. the relevant Vectra grades are generally suitable for food contact use in the EU.

USA:
Many Vectra grades are compliant for food contact with the FDA (Food and Drug Administration). They are approved for for food contact use under the system of premarket notifications through the following Food Contact Notifications (FCN): FCN no. 103 and FCN no. 423. These FCNs can be viewed in detail on the FDA website. (http://www.cfsan.fda.gov)

3.6.2 Drinking water applications

Vectra grades are generally suitable for use in contact with drinking water. Various countries operate different approval application procedures but all are based on the same principle. The final customer sends his product to the testing institute, which then – on request – obtains the relevant formulation from the material manufacturer (= Celanese) and carries out the test. The final customer is then informed of the test result and, if the product has passed, is given a corresponding test certificate from the testing institute.

In some countries, Celanese has performed the relevant tests on test specimens produced from standard grades to give final customers the best possible guarantee that their products will also pass this test. However, possession of such a manufacturer's material test certificate does not exempt final customers from testing the end product.

The most important approval application procedures within the EU (those of the UK, France and Germany) and the US procedure differ in a number of details, which have already been or will be taken into account in the manufacturer's material approval tests:

UK – WRAS:
In the UK, all materials must be listed at WRAS (= Water Regulations Advisory Scheme), before a test can be carried out. Various Vectra grades are listed and have been "pretested" for use in contact with drinking water up to a temperature of 85°C – these can be viewed on the WRAS website. (http://www.wras.co.uk)

Germany – KTW
In Germany, a few representative Vectra grades have passed the so-called KTW tests (KTW = plastics in contact with drinking water), which were carried out on test plaques. The plaques were subjected to both the cold and hot (90°C) water tests. We can supply the KTW certificate awarded for the tests on request. The microbiological test as per Worksheet W270 of the German Technical Association for Gas and Water (DVGW Arbeitsblatt W270) has also been carried out on a representative Vectra grade.

USA – NSF
Regarding drinking-water applications in the USA there is an exemplary test of a Vectra grade according to NSF standard 61 in process (NSF = Natio nal Sanitary Foundation). On the basis of several existing approvals in other countries we expect a positive result of the tests and the corresponding listing at NSF in approx. 4–6 months.

FR – ACS
So far no tests have been carried out in accordance with the French ACS (Attestation Conformite Sanitaire) requirements.

Important information: The German drinking water (KTW) regulations apply to products used in the drinking water system from the public reservoir via the pipeline distribution system and domestic installations to the end of the faucet. Once the water has left the faucet, materials and articles coming into contact with drinking water are covered exclusively by the German Regulations for Materials and Articles Coming into Contact with Food (Lebensmittel Bedarfsgegenstände-Regularien) (see also section 3.5.1).

3.6.3 Medical / pharmaceutical applications

Vectra MT products have been specially formulated for use in the medical and pharmaceutical sectors. As a result, they fulfil additional criteria besides conformity with food contact requirements:

– formulation consistency
– freedom from additives of animal origin (BSE freedom)
– listing in the FDA Drug Master File (DMF)
– listing in the FDA Device Master File (MAF)
– biocompatibility test as per the USP (United States Pharmacopeia) class VI and /or ISO 10993 (ISO 10993-5; -10; -11)

In addition, cytotoxicity and pyrogenicity tests have been carried out for some grades.

3.6.4 Underwriters Laboratories (UL) flame classification

Vectra is inherently flame-retardant. Most commercially available Vectra products are listed with UL flame class V-0. Details of the properties and classification of the materials are given on the relevant Yellow Cards and can be viewed on the UL website (http://www.ul.com)

Further information can be obtained from Celanese's Technical Customer Service team.

3.6.5 Canadian Standards Association (CSA) flammability classification

The Canadian Standards Association (CSA) has approved most commercially available Vectra products. To obtain information on individual grades, please contact Celanese's Technical Customer Service team.

3.6.6. Industry standards

Vectra products comply with many electrical/electronics and automotive industry standards on the absence of harmful substances, including the Joint Industrial Guide (JIG) list for the electrical/electronics industry and the Global Automotive Declarable Substance List (GADSL). In addition, some products have an IMDS (International Material Data System) entry.

3.6.7. Recycling

In terms of hazardous substances, Vectra grades meet the requirements of the EU Waste Electrical and Electronic Equipment (WEEE) Directive, the Restriction of Hazardous Substances (RoHS) Directive and the End-of-Life Vehicle (ELV) Directive.

For information about other approvals or questions of conformity relating to individual products, please contact Celanese's Technical Customer Service team.t

4. Behavior in relation to environmental effects

4.1 Hydrolysis

Vectra has exceptional resistance to hydrolysis, compared with other polyesters. Figs 4.1.1 to 4.1.4 show the results of immersion tests in hot water and steam.

Prolonged exposure at high temperatures leads to gradual hydrolytic degradation.

Vectra has exceptionally low equilibrium moisture content (see enclosed product information).

Fig. 4.1.1 • Tensile Strength versus Immersion Time in Hot Water (120°C, 2 bar)

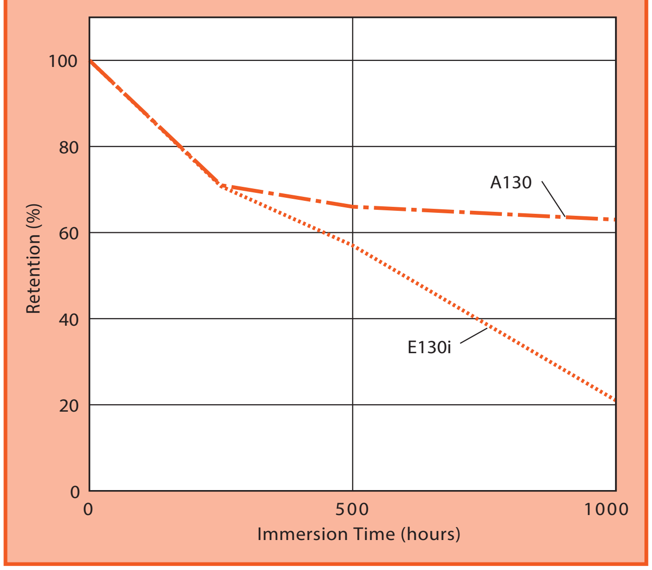


Fig. 4.1.2 • Tensile Modulus versus Immersion Time in Hot Water (120°C, 2 bar)

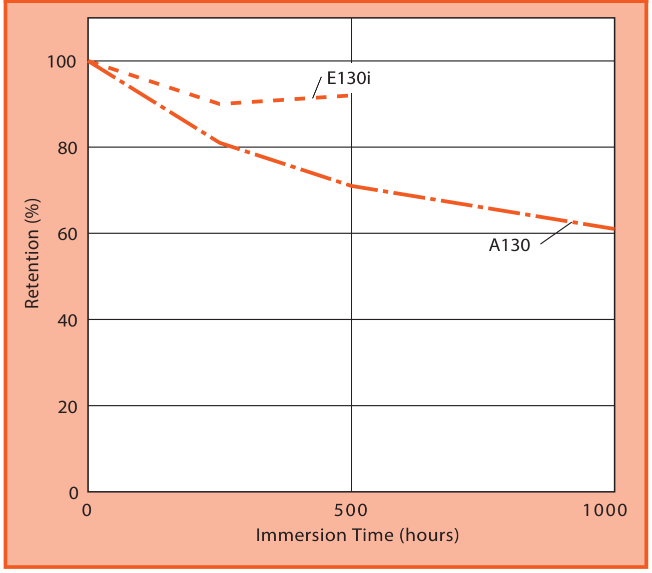


Fig. 4.1.3 • Tensile Strength versus Immersion Time in Steam

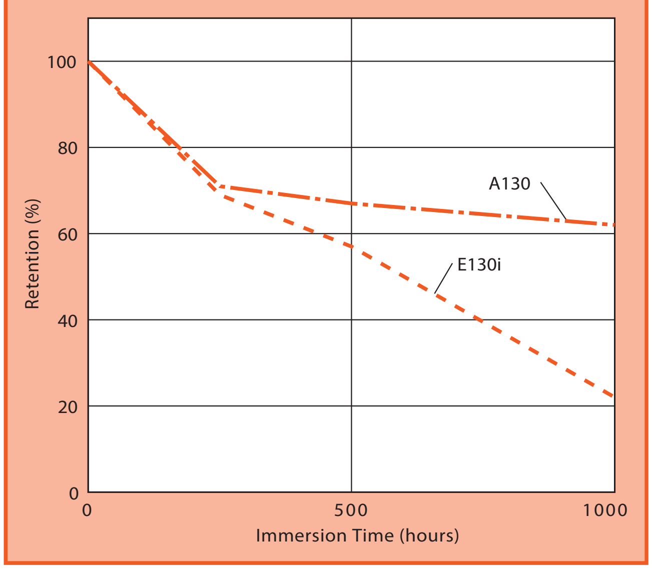
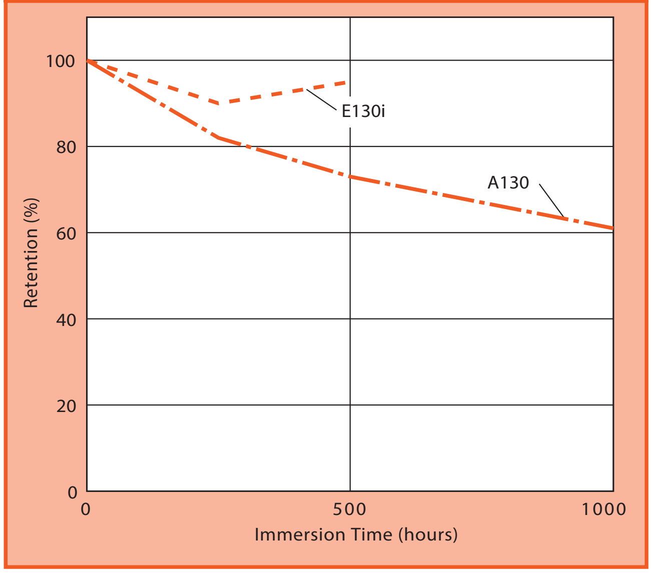


Fig. 4.1.4 • Tensile Strength versus Immersion Time in Steam



4.2 Chemical and solvent resistance

Vectra has very good resistance to chemicals, particularly to organic solvents (even at high temperatures) and to the cleaning agents normally used in the electronics industry. Its resistance to concentrated mineral acids and alkaline (both inorganic and organic) at elevated temperature is problematic.

The resistance of Vectra to methanol and methanol-containing fuels depends very much on the temperature and degree of contact. In applications involving constant contact with methanol-containing fuels, the temperature should not exceed 70°C. The results of testing in various chemicals, solvents and fuels are given in Table 4.2.1. The results were determined on injection molded test specimens without any externally induced stress. The additional effect of mechanical stresses can alter chemical resistance. The data are therefore intended for initial guidance only. Before commercial use, moldings or test specimens produced from Vectra should be tested under actual service conditions. Changes in concentration, temperature or the particular formulation can significantly affect
chemical resistance.

Five test bars (127 mm x 12.7 mm x 3.2 mm) were immersed in the medium for a given perod of time without any externally induced stress. Changes in weight, dimensions, flexural strength, flexural modulus and hardness were measured.

Table 4.2.1 • Chemical Resistance

Rating: + Resistant – less than 2% change in weight and dimension, less than 5% change in mechanical properties.
o Limited resistance
– Not resistant

Medium	Conditions (time/temperature)	Vectra® LCP grade	Rating
Acetic acid	(100%) 30 days/118°C	A950	+
	20 days/23°C	A625	+
Acetone	180 days/56°C	A950	+
		A130	+
		A625	+
Acetonitrile	120 days/23°C	A625	+
Brake fluids:			
Castrol® TLX 988C	30 days/121°C	A130	o
		A950	+
		B950	+
	90 days/121°C	A130	–
NAPA® brand DOT-3	90 days/121°C	A130	o
Chlorine gas	180 days/23°C	A950	+
		A130	+
		A625	+
Chlorine/water (saturated solution)	180 days/23°C	A950	+
		A130	+
		A625	+
Chromic acid (50%)	90 days/50°C	A625	+
	180 days/50°C	A950	+
		A130	o
		A625	o
	30 days/70°C	A950	+
		A130	+
	60 days/70°C	A950	+
		A130	o
Chromic acid (70%)	30 days/88°C	A950	+
		A130	o
		A625	o
Dimethyl formamide (DMF)	180 days/66°C	A950	+
		A130	+
		A625	+
Diphenylamine	180 days/66°C	A950	+
		A130	+
		A625	+
Diphenyl carbonate	10 days/250°C	A950	–
Ethanol	30 days/52°C	A950	+
Ethyl acetate 1	80 days/77°C	A950	+
		A130	+
		A625	+
Ethylene diamine	30 days/100°C	A950	–
	180 days/23°C	A950	+
		A130	o
		A625	+

Table 4.2.1 • Chemical Resistance (Continued)

Medium	Conditions (time/temperature)	Vectra® LCP grade	Rating
Ethylene glycol (Antifreeze/water)	30 days/50°C	A950	+
	30 days/121°C	A950	o
	(50/50)	B950	o
		A150	–
Fluorinert® FC-70	1 day/215°C	A950	+
		A130	+
Formic acid (80%)	30 days/104°C	A950	+
		A625	+
	270 days/104°C	A950	o
		A625	o
	455 days/104°C	A950	–
Fuels:			
Fuel C (ASTM D471)	30 days/121°C	A950	+
50/50 iso-octane/toluene		B950	+
	90 days/121°C	A130	o
Fuel C + 20% methanol	125 days/60°C	A130	+
		A230D-3	o
Fuel C + 20% ethanol	125 days/60°C	A130	+
		A230D-3	o
M-85 fuel	20 days/121°C	A130	–
Lead free gasoline (petrol)	30 days/121°C	A950	+
		B950	+
	90 days/121°C	A130	+
Lead free gasoline (petrol) + 10% methanol	30 days/121°C	A950	o
		B950	o
	90 days/121°C	A130	–
	90 days/93°C	A130	o
		A625	+
Gasoline (petrol) w/70/30 heptane/toluene, copper ion, t-butyl-hydroper oxide	30 days/121°C	A950	+
		B950	+
Hexafluoro-isopropanol	10 days/25°C	A950	–
Hexane	10 days/23°C	A625	+
Hydrochloric acid (37%)	30 days/88°C	A950	+
		A130	o
		A625	o
	120 days/88°C	A950	o
		A130	o
		A625	o
Hydrofluoric acid (anhydrous)	30 days/23°C	A950	–
Hydrogen chloride (anhydrous)	30 days/23°C	A950	–
Iso-octane	14 days/60°C	A625	+
120 days/23°C		A625	+
Methanol	30 days/64°C	A950	+
		B950	+
	90 days/64°C	A130	+
	45 days/110°C	A130	–

Table 4.2.1 • Chemical Resistance (Continued)

Medium	Conditions (time/temperature)	Vectra® LCP grade	Rating
Methylene chloride	180 days/40°C	A950	+
		A130	o
		A625	+
Monochloroacetic acid	180 days/50°C	A950	+
		A130	+
		A625	+
Morpholine (200ppm/steam) (tetrahydrooxazine)	10 days/132°C	A130	+
Nitric acid (50%)	120 days/23°C	A625	+
	60 days/70°C	A950	+
		A130	+
		A625	+
	180 days/70°C	A950	+
		A130	o
		A625	+
Nitric acid (70%)	30 days/88°C	A950	o
		A130	–
		A625	o
Nitrobenzene	30 days/66°C	A950	+
Nitroglycerine	30 days/66°C	A950	+
Oils:			
Engine Oil, 10W-30	30 days/121°C	A950	+
		B950	+
		A130	+
Shock absorber-Oil (Shell® GHD 15)	40 days/150°C	A130	+
Silicone-Oil	30 days/200°C	A950	+
Hydraulic-Oil (Skydrol®) B950 +	30 days/71°C	A950	+
Transmission-Oil	30 days/149°C	A625	+
(Dexron® II)	90 days/149°C	A625	+
Pentafluorophenol	10 days/60°C	A950	–
Phenol	100 days/100°C	A950	+
		A130	o
		A625	+
Refrigerants:			
Refrigerant R-22	30 days/80°C	A950	+
		A625	+
Refrigerant R-12 + 5% refrigerator oil	60 days/100°C	A625	+
Refrigerant 113	180 days/47°C	A950	+
		A130	+
		A625	+
Refrigerant R134A + 5% refrigerator oil	60 days/100°C	A625	+
H-FCKW 123	10 days/50°C	A130	+[1]
Sodium Hydroxide (5%)	90 days/23°C	A950	+
		A130	+
		A625	+
	180 days/23°C	A950	+
		A130 o	
		A625 o	

4

Table 4.2.1 • Chemical Resistance (Continued)

Medium	Conditions (time/temperature)	Vectra® LCP grade	Rating
	30 days/70°C	A950	+
		A130	o
	60 days/70°C	A950	o
		A130	o
	180 days/70°C	A950	o
		A130	–
		A625	–
Sodium Hydroxide (10%)	90 days/23°C	A950	+
		A130	+
	180 days/23°C	A950	+
		A130	+
		A625	o
	30 days/88°C	A950	o
		A130	–
Sodium Hydroxide (30%)	30 days/88°C	A950	–
		A130	–
		A625	–
Sodium hypochlorite (12.5%)	28 days/23°C	A130	o
	28 days/70°C	A130	–
Sulphuric acid (50%)	180 days/88°C	A950	+
		A130	+
		A625	+
Sulphuric acid (70%) 5	days/190°C	A950	–
		A130	–
		A625	–
Sulphuric acid (93%)	8 days/23°C	A950	o
		A625	o
		B950	–
	30 days/121°C	A950	–
		A130	–
		A625	–
		A950	–
Tetrahydrofuran (THF)	120 days/23°C	A625	+
Toluene	180 days/111°C	A950	+
		A130	+
		A625	+
Trichlorethane	90 days/66°C	A950	+
Urea (46%)	60 days/88°C	A950	o
		A130	–
		A625	o
Water	10 days/121°C	A950	+
	40 days/121°C	A950	o
		A625	+
	60 days/121°C	A950	o
		A130	o
Water vapor	70 days/121°C	A950	o
		A130	o
		A625	+

4.3 Permeability to gases and vapors

Vectra has extremely low permeability to gases and water vapor. Figure 4.3.1 shows the superior performance of unfilled Vectra polymers compared with conventional barrier materials such as ethylene vinyl alcohol copolymer (EVOH), polyvinylidene chloride (PVDC), MXD6 (a copolyamide of meta-xylenediamine and adipic acid), and PCTFE (polychloro - trifluoroethylene). The greater impermeability of Vectra makes it possible to use thinner barrier layers in coextruded structures. In the production of liquid crystalline monolayer film, the problem of fibrillation must be addressed. This anisotropy can be overcome by post-extrusion techniques such as biaxial orientation (see section 7, Extrusion). The water permeability of Vectra is shown in Table 4.3.1.

4.4 Radiation resistance

Vectra has excellent resistance to gamma radiation. Table 4.4.1 shows the effect of Cobalt 60 radiation on the mechanical properties of Vectra A950.

4.5 Ultraviolet and weathering resistance

On exposure to weathering, Vectra, like other plastics, shows a surface change over time. The main reason for this is UV radiation. It causes a white deposit of degraded material to form on the surface ("chalking") with consequent loss of gloss, color change and deterioration in mechanical properties.

After artificial weathering for 2000 hours, samples molded from Vectra retained over 90% of their initial mechanical property values (Table 4.5.1). After one year's outdoor weathering, a slight white deposit was detected.

(1) Weight change in 60 x 60 x 4 mm plaques only

Castrol® TLX is a registered trademark of Castrol Limited.
NAPA® is a registered trademark of National Automotive Parts Association.
SKYDROL® is a registered trademark of Monsanto Co.
DEXRON® is a registered trademark of General Motor Corp.
Fluorinert® is a registered trademark of Minnesota Mining and Manufacturing Co.
Shell® is a registered trademark of Shell Oil Co.

Fig. 4.3.1 • Permeability of Various Polymer Films (Thickness 25 µm)

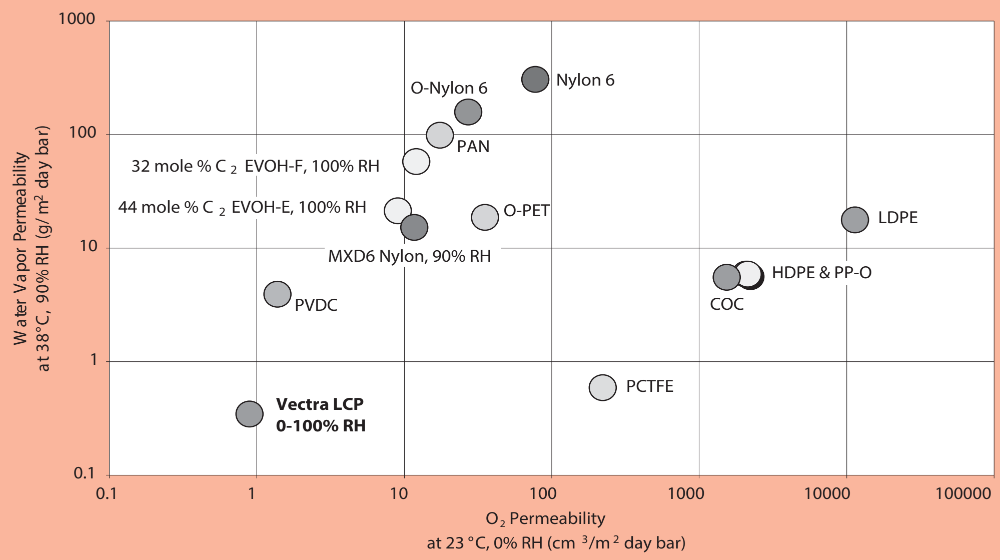


Table 4.3.1 • Permeability of Various Polymer Films (Thickness 25µm)

Material	O_2 Permeability 23° C, 0% RH cm³/m² day bar	Water Vapor Permeability 38°C, 90% RH g/m²day bar
Vectra LCP	0.9	0.3
COC	1515.4	1.1
EVOH-E 100%RH	9.1	21.4
EVOH-F 100%RH	12.0	57.9
PVDC	1.4	3.9
MXD6	11.7	15.3
MXD6 + Co	0.3	15.3
PAN	17.5	98.4
Nylon 6-oriented	27.2	158.1
Nylon 6	77.3	307.1
PET-oriented	35.2	18.6
PCTFE 2	21.5	0.6
PP-oriented	2067.1	5.9
HDPE	2137.0	5.9

Table 4.3.2 • Hydrogen Permeability

Material	Test Conditions	H_2 Permeability cm³/m²·d·bar	Film Thickness
Vectra A950	40°C, 0% RH	78	50 µm
Vectra A950	150°C, 0% RH	98	2.5 mm
Vectra E130i	150°C, 0% RH	104	2.5 mm

Table 4.4.1 • Cobalt 60 Radiation Vectra® A950 (Percent retention of properties)

Radiation Dose	25 Mrads	100 Mrads	250 Mrads	500 Mrads
Tensile strength[1]	97	95	95	95
Tensile modulus[1]	100	100	106	106
Break elongation[1]	81	81	79	79
Flexural strength[2]	101	102	102	102
Flexural modulus[2]	108	108	116	125
HDT @ 1.82 MPa[3]	100	100	100	94

(1) ASTM D638   (2) ASTM D790   (3) ASTM D648

Table 4.5.1 • Results of Artificial Weathering for 2,000 hours (ASTM D2565 – xenon arc lamp, air temperature 125°C, water spray for 18 minutes every 202 minutes) (Percent retention of properties)

	Vectra A950	Vectra A130
Tensile strength[1]	95	95
Tensile modulus[1]	90	98
Flexural strength[2]	95	95
Flexural modulus[2]	95	95
HDT @ 1.82 MPa[3]	90	92
Notched Izod[4]	90	95

(1) ASTM D638   (2) ASTM D790   (3) ASTM D648   (4) ASTM D256

5. Processing

Vectra is very suitable for conventional processing methods such as injection molding and extrusion. The most commonly used processing method for Vectra is injection molding. Fast cycles, good processability and the possibility of blending with (sorted) regrind increase cost efficiency.

Because of the material's good flow properties and low tendency to form flash, very long, thin-walled parts can be produced.

5.1 Safety recommendations

Processing of Vectra poses no particular safety risk, Provided standard industry safety practices are observed. However, like most polymers, Vectra decomposes when heated to excessively high temperatures. If insufficient ventilation is available, decomposition products can build up that then may be harmful to health. A suitable ventilation system is therefore required.

To prevent thermal decomposition, off-gassing and pressure build-up in the barrel, melt temperatures should not exceed 330°C for A polymers, 360°C for Ei polymers and 380°C for S polymers. These temperatures are well above the normal processing range. For more extended shutdowns (> 10 min), run the screw dry and lower the barrel temperatures by at least 100°C. See section 6.2 for recommended processing conditions.

Other important precautions:

- Sufficient time should be allowed to heat up the machine. The barrel should have reached the required processing temperature settings 5 minutes before feeding in the pellets and turning the screw.
- When handling hot material and molds, gloves, protective clothing and goggles should be worn.
- When switching off the machine, the injection unit should be retracted.

Material Safety Data Sheets (MSDS) are available for all Vectra grades. Always consult the MSDS before working with any Vectra grade.

5.1.1 Startup and shutdown procedures

Startup

The barrel temperatures are set to the level required for processing. When the set values have been reached, it is advisable to wait for 5 minutes before filling the plasticizing barrel. When the barrel has been filled, several shots are ejected into the open (air shot). Special attention should be given to the nozzle temperature because if it is too cold the melt will freeze and block the nozzle. When the temperature of the melt ejected into the open has been checked with a needle pyrometer and the melt is flowing perfectly, processing can start.

Short and long interruptions

For interruptions of less than 10 minutes no special measures are required. For longer interruptions thorough evacuation of the barrel followed by a 100°C temperature reduction is recommended.

Changing from another thermoplastic to Vectra

Since many other plastics are less thermally stable at the processing temperatures used for Vectra, it is advisable to purge them from the machine beforehand as thoroughly as possible. A suitable purging material is polypropylene (glass fiber reinforced grades have a better cleaning effect).

The purging material is purged into the open at the relevant melt temperature until it runs clean. Before increasing the barrel temperatures to the values recommended for Vectra, the injection unit must be run until empty. When the set temperatures are reached, run Vectra with the unit retracted from the mold until the melt is free of all traces of the purge material. Once this has happened, injection molding can begin.

Changing from one Vectra grade to another

It is possible to process different Vectra grades using one grade to remove another without purging with first material is completely pumped out and then displaced by the second material. In case of a color change (particularly from black to natural), it is important to ensure that the color of the previous material has been completely removed from the machine.

Shutting down the machine

If Vectra is to be processed again after the machine has been shut down, the injection unit must simply be run until empty. Then the nozzle and barrel heaters can be switched off. If a change to another thermoplastic is planned, the Vectra must first be purged with polypropylene. The temperatures should remain set at Vectra processing temperatures because if they are reduced prematurely traces of Vectra can no longer be purged out.

5.1.2 Fire precautions

Vectra is inherently flame retardant. Nevertheless, is advisable when storing or processing the plastic to take the necessary fire precaution measures. Particular care should be taken to observe the specific regulations applicable in the processing or storage location. Certain end products and fields of application may impose special requirements from the fire prevention standpoint. It is the responsibility of the raw material converter to ascertain and observe such requirements.

5.2 Drying

Vectra resins are well known for their low water absorption. In order to ensure optimum molded part properties, the resin and any regrind should be dried correctly prior to processing. If the resin is not properly dried, residual moisture can cause voids, outgassing (so-called blisters) and in extreme cases polymer degradation. These effects can result in poor part quality. It is therefore important for the material to be dried under the recommended conditions and appropriate equipment.

In order to ensure the quality of molded parts, a dessicant air dryer with two or more desiccant beds is strongly recommended. Such dryers allow drier air than single bed dryers to be delivered to the plastic, so reducing both moisture content and the necessary drying time. The material should also be allowed to reach the recommended drying temperature before the drying time is started. When resin is placed in a hopper at room temperature, it may take 2 to 6 hours for the material to reach the necessary drying temperature. This time will vary according to the thermal properties of the plastic, the mass of material being dried, and the design of the hopper. In addition, it is important to note the location of the thermocouple that measures the temperature of the air being delivered to the hopper. Dryer systems that do not measure the air temperature at the inlet of the hopper might not accurately represent the delivery air temperature. This is because significant heat loss can occur between the exit of the dryer unit and the inlet of the hopper. Heat loss, even through insulated tubes, can result in up to a 50°C lower drying temperature.

Summary of drying recommendations

1. The resin inside the hopper should be allowed to reach the drying temperature, before the minimum drying time is started.

2. A desicant dryer with two or more desiccant beds capable of reaching -40°C dew point or below is recommended.

3. Vectra resin should be dried in accordance with the information in the following table. To ensure effec tive drying, the residual moisture content of the dried material should be less than 0.01% (100 ppm).

Table. 5.2.1 • Drying conditions

Vectra® LCP	A series V140	B series	Ei & S series V143XL	V400P
Temp. (°C)	150	150	150 / 170	90
Time (hours)	4–24	6–24	6–24 / 4–16	8–24

4. Ensure the delivery air temperature readout represents the actual temperature of the air being delivered to the hopper.

Regrind should be dried for 2 hours longer than the drying conditions recommended for virgin material, because of its porosity and greater surface area.

6. Injection Molding

6.1 Machine requirements

Vectra can be processed much like any other thermoplastics using common injection molding machines.

6.1.1 General

Abrasive wear, particularly by glass, can occur on the lands and edges of injection screws. In time, the root diameter will wear in the feed, compression and metering zones. The highest level of wear and location of wear on the screw will depend on the type of material and barrel utilization. The screw should therefore be made of a heat-treated alloy steel with a hard surface.

The barrel should be fitted with all heating zones independently controlled to ensure precise temperature control. This is especially critical for the higher temperature Vectra grades.

Despite the thermal stability of the melt, it is important to aim for the shortest possible melt residence time (between 3 and 5 min) in the barrel, i.e. the capacity of the machine should be matched to the shot weight of the injection molding.

Since Vectra is a fast-cycling material, the machine should have a high plas icating capacity.

6.1.2 Screw design

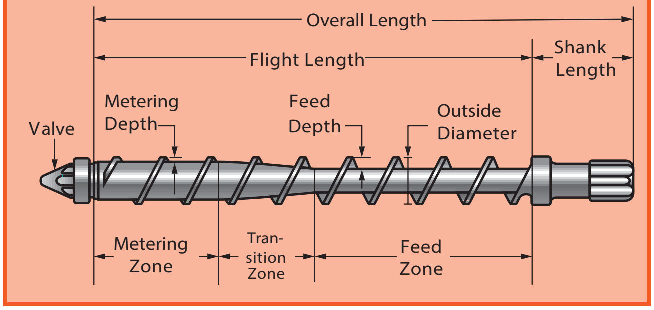
The design of the screw is not crucial for processing Vectra but some general rules should be observed: (see Fig. 6.1.1). A three-zone screw divided into feed, compression and metering zones is preferred. How - ever, a higher percentage of feed flights may be necessary for smaller machines.

Zone division:
– 1/2 feed
– 1/4 compression
– 1/4 metering

The screw length/diameter ratio (L/D) should be between 16:1 and 24:1. 20:1 L/D is preferred and most common for conventional molding.

The preferred compression ratio ranges from 3:1 for larger machines to as low as 2:1 for smaller machines (see F g. 6.1.1).

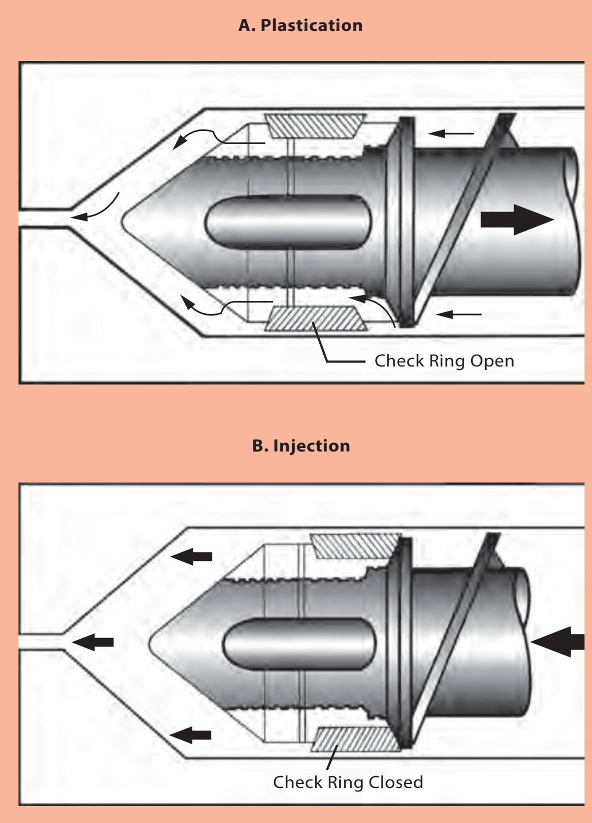
Fig. 6.1.1 • Metering Type Screws Recommended for Processing Vectra® LCP



6.1.3 Check ring

Because Vectra plastics have such low viscosity, it is essential for the check ring non-return valve to function correctly (Fig. 6.1.2). The check ring is working properly if it holds a constant melt cushion. Malfunctioning check rings result in inconsistent parts, short shots and poorly formed weld lines.

Fig. 6.1.2 • Check Ring Non-Return Valve Used on Reciprocoating Screw Injection Molding Machine



5
6

6.1.4 Nozzle

Vectra can be processed with a free-flow or needle shut-off nozzle. In the case of free-flow nozzles, those with a small aperture (1.5 to 2.5 mm) are recommended to prevent drooling of the melt. Nozzles should be as short as possible and have a heating band with its own temperature control system. If drooling or stringing occurs, the problem can normally be eliminated by

6.1.5 Hot runner systems

Vectra can be processed successfully in hot runner systems to conserve material and reduce the labor input. Externally heated hot runner systems as well as combinations of internally and externally heated systems are preferable to internally heated (torpedo) systems for processing Vectra. Externally heated hot runner systems achieve an even flow of material with a constant melt temperature over the cross-section of the hot runner. The heat energy is evenly distributed from outside to inside, so ensuring homogeneous temperature distribution in the melt. The choice of the correct tool steel is important in the design of hot runner tools for processing Vectra (HRc > 56).

The hot runner system designer should also consider the shearing of the material and associated effect on viscosity. The runner diameter in hot runner systems should be designed according to shot weight in the same way as for cold runner systems. Low shot weights require runner diameters in the hot runner nozzle of about 3 mm. In the hot runner manifold block, runner diameters of 3-5 mm are usual. On the other hand, with large shot weights (over 100 g), the runner diameters normally used for processing thermoplastics are recommended for the nozzle and hot runner manifold block. For small components, the hot runner gate diameter should be between 0.3 and 0.6 mm (see Fig. 6.1.3), while for large moldings, gate diameters of about 0.8 to 2 mm are recommended. Because of the required material shear, nozzles with tips or torpedos are customary but needle shut-off nozzles may also be used.

Care should be taken to ensure that the molten material is not retained for too long in the hot runner during processing. If possible, the total residence time in the melt should be less than 5 minutes to minimize the thermal stress on the material. It is important to ensure that uniform flow occurs right from the start of filling (swelling flow). This is achieved by correct positioning of the gate, so that it injects against a core or a wall. Jetting should be avoided. Flow to the part can be achieved either directly from the hot runner or via a cold sub-runner. The recommendations for Vectra runner geometry apply to sub-runners (Fig. 6.1.4). All cavities should be designed so that flow resistance remains constant. Otherwise, the low viscosity of Vectra can result in the melt moving ahead in regions of low flow resistance, possibly leading to warage problems.

Fig. 6.1.3 · Hot Runner System for small parts

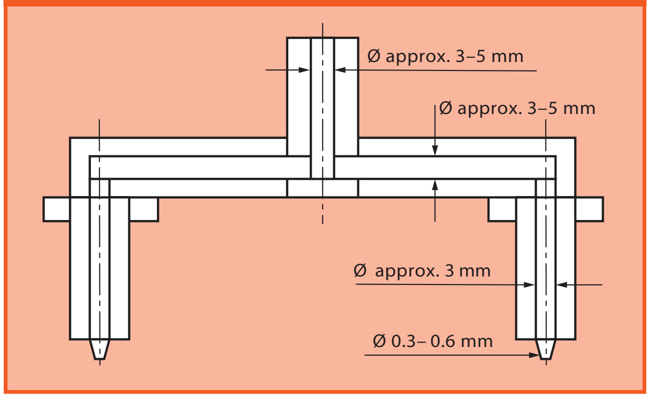
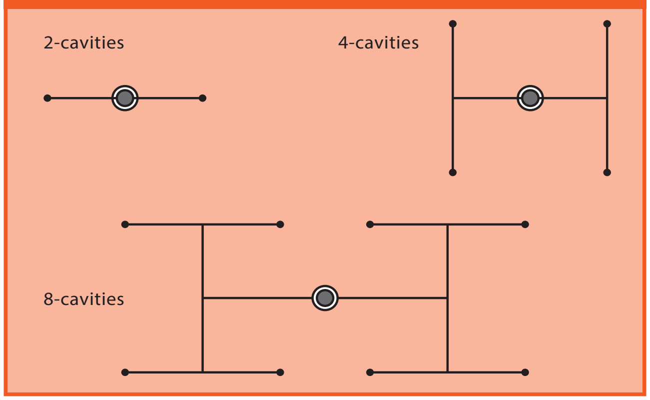


Fig. 6.1.4 · Hot Runner Distributor

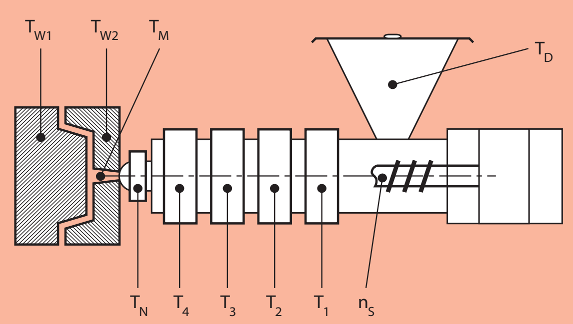


Parts manufactured from Vectra with hot runner systems are typically small, thin-walled parts for the electrical/electronics industry, where good high-temperature resistance is required for soldering operations. To maximize the heat resistance of the molded part, the processing temperature profile should be kept as low as possible within the recommended processing range. Residence times should also be minimized. A cold runner system that is properly designed is best for inducing shear and may be preferred over a hot manifold system. In addition, polymer stagnation in a hot manifold system may be possible since Vectra has a low heat of fusion.

6.2 Processing conditions

Vectra is notably easy to process. Typical processing temperatures are shown in Fig. 6.2.1. Recommendations for startup, shutdown and material changeovers are given in section 5.1.1.

Fig. 6.2.1 · Typical Injection Molding Conditions



	Processing Temperatures (°C) A and B series V140	Ei series V143XL	S series	V400P
T_1	270-280	315-325	330-350	185-195
T_2	275-285	315-325	340-360	205-215
T_3	280-290	325-335	345-365	205-215
T_4	285-295	335-345	355-370	205-215
T_N	290-300	335-345	335-370	200-210
T_M	285-295	335-345	360-370	200-210
T_{W1}	80-120	80-120	80-120	–
T_{W2}	80-120	80-120	80-120	–

n_S – see screw speed, Section 6.2.4
T_D – see drying instructions, Section 5.2

6.2.1 Melt temperature

Determine the melt temperature manually with a needle pyrometer when the machine has been cycling for several minutes. If there are any deviations from the set value, the barrel and nozzle heater settings must be adjusted accordingly. Melt temperature should generally be checked in this way, because the melt thermocouples integrated into the injection molding machine do not always show the true value.

If the molded parts are to be exposed to elevated temperatures above 220°C, e.g. during a subsequent soldering operation, then it is imperative that Vectra is thoroughly predried and not overheated during processing. Melt temperatures should, if possible, be maintained within the lower range of the temperatures recommended in Fig. 6.2.1 and the melt residence time in the barrel should be 3 to 5 min.

6.2.2 Injection rate

To improve weld line strength and flow, very fast injection rates should be used for small moldings (0.2 to 0.3 sec fill time). With increasing shear, the melt viscosity of Vectra rapidly decreases. For parts that are difficult to fill, the injection rate can be increased to improve flowability. Increasing the injection rate and mold temperature may be more effective than raising the melt temperature and preserves the quality of the plastic at the same time.

6.2.3 Mold temperature

Vectra can be processed over a wide range of mold temperatures, with temperatures between 65°C and 120°C being the most common. Higher mold temperatures usually result in a smoother surface finish and achieve improved flow performance.

6.2.4 Screw speed

The screw speed should be sufficiently high to achieve complete plastication of the melt before injection starts. Typical speeds are 100 to 200 rpm at a screw diameter of 15 to 25 mm.

6.2.5 Back pressure

Back pressure is not normally necessary during plastication and should be set to a minimum (5 to 15 bar spec.). With fiber reinforced grades, excessive back pressure leads to fiber breakage as well as overheating of material.

6.2.6 Screw decompression

Screw decompression is not generally recommended. If screw decompression is necessary to prevent drooling, it should be restricted to a minimum (2 to 4 mm). Excessive decompression can draw air or moisture into the nozzle and result in a cold slug or blistering on the surface of the molded part.

6.2.7 Injection pressure

The optimum injection pressure depends on the specific Vectra grade as well on the design of the molded part, the mold and machine conditions. All Vectra grades have low melt viscosity and generally require lower injection pressures than other thermoplastic materials.

6.2.8 Holding pressure

The holding pressure can be equal to or less than the injection pressure. The required holding pressure times are shorter than for semi-crystalline thermoplastics since Vectra freezes very quickly. The required holding pressure time can be determined by part weight consistency.

6.2.9 Cycle time

In addition to low viscosity, all Vectra grades have a very low heat of fusion (about 5 to 10% of the heat of fusion of PET or PBT). This means that relatively little heat has to be removed from the molded part through the walls of the mold to freeze the part. Ejection can take place at high temperatures if the ejectors are designed not to make an indentation in the molding. The extremely low internal stresses occurring with Vectra make it possible to operate the injection mold at relatively low temperatures. These characteristics lead to exceptionally fast cycle times. As the wall thickness is changed, the cooling time changes approximately with the square of the thickness. This also has an impact on the total cycle time.

6.3 Regrind

The regrinding processes for Vectra are similar to those for other high-modulus thermoplastics. Liquid crystal polymers are tough, fibrous materials that require some care in handling to produce high regrind quality. Several variables will affect regrind quality. These include the particular grade of Vectra being processed, the type of filler or reinforcement, the geometry of the part and/or runner, the type of machine and the reprocessing technology used. The processor must determine the upper limit for regrind addition on a case by case basis by evaluating part performance, regulatory limits and molding process stability.

6.3.1 General recommendations

1. Runners, sprues and reject parts will cut best when fed to the granulator while still hot, i.e. just out of the mold. Granulating while hot will produce the smooth est chip edges and generate the least amount of tails and fines. If this is not practical, the scrap may be reheated in an oven to approximately 150°C and then cut while hot. When grinding, take care to feed the parts into the granulator slowly. This will minimize residence time in the granulator, so improving cutting quality (otherwise the scrap tends to be crushed rather than cut).

2. In order to avoid feeding and screw recovery issues the particle size of regrind should be as close as possible to the virgin pellets with smooth chip edges.

3. Sharp blades improve regrind quality and will cut rather than shatter the scrap.

4. Close tolerance gaps between blade and bed knife improve regrind quality. Set to the closest gap recom mended by the granulator manufacturer.

If the above procedures are not successful, it may be necessary to reduce the speed. Machines that operate at or below 30 rpm tend to improve chip quality by shear cutting the larger oversized granules during regrinding rather than smashing or shredding them. High speed granulators tend to shatter the scrap rather than shearing it – especially when it is cold (less than 100°C). This results in rough-edged, fibrous Vectra regrind with a high level of fines.

The following table indicates the approximate percentage by weight of fines and chip quality obtained in a test. Naturally, results will vary according to the equipment used and processing parameters. Fines are particles that pass through a 10-mesh screen (10 apertures/inch2). Excessive fines and poor chip quality may cause difficulty in feeding regrind into an injec- tion molding machine.

		Cut Hot	Cut Cold
Low Speed Granulator	Fines, weight %	5	13
	Chip Quality	Good	Fair
High Speed Granulator	Fines, weight %	5	17
	Chip Quality	Fair	Poor

6.3.2 Equipment

A number of users have reported success using an S-Cutter from Usni Tech LLC for regrinding Vectra runners, sprues and reject parts.

Contact address of Usni Tech LLC:
818 Terminal Rd
Lansing, MI 48906, USA
Tel: ++1/517-332-7400
or: www.usnitech.com

In Europe, the machines can be purchased from

Scholz Apparate & Anlagenbau GmbH
In der Hernau 5
D-90518 Altdorf
Germany
Tel: ++49 (0) 9187-4037

6.3.3 Using regrind

Four factors have the potential to cause loss of properties in regrind material: contamination, thermal decomposition, hydrolysis (reaction with water) and damage to reinforcing material, especially glass fibers. Vectra plastics have excellent thermal and hydrolytic stability when molded and dried under the recom- mended conditions. Glass fiber reinforced products may exhibit some loss of notched Izod impact strength due to breakup of the glass fibers.

To maintain color uniformity and optimum mechani- cal properties, limit regrind addition to 25%. Under- writers Laboratories accepts up to 25% regrind for UL listed applications without further testing.

In certain cases, 50% regrind addition is possible. Some of these grades are listed by UL as being approved for use with a 50% regrind ratio (and even 75% in the case of Vectra E150i).

Whenever using regrind material, the end user must test the finished parts to ensure satisfactory perfor- mance. Best practice for using regrind includes:

1. Adequately dry both the regrind and virgin plastic, preferably to less than 0.01% moisture. Refer to section 5.2 for recommended drying procedures.

2. Regrind material must be free from contamination and any foreign material, including other plastics, metal, and even other liquid crystal polymers.

3. Avoid excessive melt temperatures.

4. The melt residence time in the barrel should be as short as possible, preferably between 3 and 5 min.

6

5. Do not use screw decompression.

6. Dust should be avoided as much as possible. In addition, the material should preferably be reground immediately after injection molding, while still hot.

7. Refer to section 6.2 for recommended injection molding conditions.

When molded using the recommended conditions, Vectra maintains about 80-100% of its strength and modulus. Glass fiber reinforced grades may exhibit a reduction in notched Izod impact due to fiber breakage during processing. After repeated molding of the same material, a slight discoloration has been observed.

Whenever regrind is used, and especially with regrind ratios higher than 25%, the following guidelines should be observed:

1. Run parts for quality testing under steady state conditions. Continue production with a constant feed of regrind material at the desired ratio for several hours to establish the distribution of residence time.

2. Qualify the regrind-containing parts,by using the same test methods as for parts produced from virgin material.

3. Adhere to any applicable regulatory requirements.

6.4 Troubleshooting

Many processing problems are caused by easily corrected conditions such as inadequate drying, incorrect temperatures or pressures, etc. Often solutions can be found by following the recommendations given below.

Adjustments should be moderate and made a step at a time, giving the machine time to stabilize before further adjustments are made. Check that the machine is opera ing within the parameters recommended for the specific Vectra grade. For example, melt temperature should be checked on air shots collected at specified intervals when the process is stabilized.

6.4.1 Brittleness

– Check for contamination
– Decrease amount of regrind in the feed
– Decrease back pressure
– Decrease melt temperature by
  • Decreasing screw speed
  • Decreasing the barrel temperature
– Dry the plastic and regrind before use

6.4.2 Burn marks

Vectra materials are highly oriented and may have a slightly dark discoloration in the gate region.

– Check the material for contaminants
– Decrease injection rate
– Improve venting to minimize trapped gas
– If necessary, relocate gate to improve venting

6.4.3 Dimensional variation

– Confirm complete screw recovery in allotted time
– Confirm that check ring seats uniformly
– Maintain a 3 to 5 mm melt cushion
– Fill the mold as rapidly as possible
– Increase cooling time
– Check the machine’s hydraulic and electrical systems for erratic performance
– Reduce the number of cavities in the mold
– Balance the layout of runners, gates and cavity
– Improve venting
– Increase injection pressure

6.4.4 Discoloration

– Check for contamination of plastic feed
– Purge heating barrel
– Decrease melt temperature by
  - Decreasing the screw speed
  - Decreasing the barrel temperature
– Minimize residence time and cycle time
– Improve venting in the mold
– Reduce residence time, if necessary by changing to a smaller injection molding machine

6.4.5 Flashing

Although Vectra has very good flowability in molding thin-walled parts, the material has no tendency to flash, provided that the venting recommendations are correctly followed (see section 9.2.7).

The reason for this is Vectra's low enthalpy, which guarantees immediate freezing of the polymer melt on the mold wall or in venting channels.

– Decrease injection pressure
– Ensure that a 3 to 5 mm melt cushion is maintained
– Reduce shot size
– Decrease injection rate
– Decrease melt temperature by
  - Decreasing the screw speed
  - Decreasing the barrel temperature
– Check mold closure for mismatch of parting line
– Improve mold venting
– Check mold for parallelism
– Move mold to a larger clamp tonnage press

6.4.6 Jetting

Vectra polymers are highly oriented, exhibit little or no die swell and tend to jet into large cavities.

– Adjust gate location so melt impinges on core, pin or wall
– Decrease injection rate
– Increase gate dimensions to 85 to 100% of wall thickness

6.4.7 Leaking check ring

– Ensure check ring is sealing properly
– Ensure check ring retains constant melt cushion of 3 to 5 mm

6.4.8 Nozzle problems

A. Nozzle drool or stringing
– Decrease nozzle temperature
– Decrease melt temperature by
  - Decreasing the screw speed
  - Decreasing the barrel and or nozzle temperature
– Add minimal decompression (too much can cause blisters on reheating molded parts)
– Dry the material thoroughly
– Use a nozzle with a smaller orifice
– Use a nozzle with a nylon type reverse taper
– Use a nozzle with a positive shut-off
– Increase cure time

B. Nozzle freeze-off
– Increase nozzle temperature
– Decrease cycle time
– Increase mold temperature
– Add sprue break (carriage back) if necessary
– Use a nozzle with a larger orifice and beryllium tip

6.4.9 Short shots

– Check hopper to confirm adequate feed
– Ensure check ring is seated
– Ensure melt cushion is consistent
– Increase shot size
- Increase injection pressure moderately
– Increase injection speed
– Increase mold temperature
– Increase barrel temperature
– Check cavity vents for blockage
– Decrease size of gate (possibly runner) to increase shear

6.4.10 Sinks and voids

Vectra has very low shrinkage values and is therefore rarely prone to sinks or voids. If these occur, they are most often an indication of short shots.

– Ensure check ring is properly seated
– Ensure screw recovery is consistent
– Ensure clearance between screw and barrel is not excessive
– Increase shot size to ensure 3 to 5 mm melt cushion
– Increase injection pressure
– Increase mold temperature
– Increase melt temperature
– Check cavity vents for blockage
– Relocate gates to thicker-walled sections
– Core out the part
– Increase holding pressure time
– Increase holding pressure
– Reduce gate size to increase shear and viscosity

6.4.11 Sticking

A. Sticking in cavity
– Decrease injection pressure
– Decrease injection rate
– Reduce holding pressure
– Eliminate undercuts; increase draft
– Check part for drag marks or unbalanced ejection
– Polish tool in ejection direction
– Improve effectiveness and balance of pullers and sucker pins

B. Sticking on the core
– Measure core temperature, decrease temperature or improve cooling
– Eliminate undercuts
– Polish cores in the ejection direction
– Increase drafts

C. Sticking in the sprue bushing
– Check the alignment and orifice size of the nozzle relative to the sprue bushing
– Decrease holding pressure
– Decrease injection pressure
– Eliminate undercuts and polish surfaces of sprue bushing
– Provide a more effective sprue puller

6.4.12 Surface marks and streaks

Vectra is highly oriented and often exhibits flow lines.

– Decrease melt temperature by
  - Decreasing the screw speed
  - Decreasing the barrel temperature
– Check for contamination
– Dry material before molding
– Reduce screw decompression
– Decrease melt residence time by
  - Decreasing overall cycle time
  - Moving tool to a smaller-capacity press

6.4.13 Warpage and part distortion

Vectra products are highly oriented and shrink much less in the flow direction than in the direction transverse to flow. Consistent and uniform melt flow is required to control shrinkage as much as possible. Most warpage is due to the flow patterns, dictated by part and gate design. For this reason, the risk of warpage is considerably greater in parts with sharp cross sectional transitions than in parts with uniform wall thicknesses. Except for mold temperature, processing condit ions have little effect on shrinkage differential.

- Relocate gate or adjust wall thickness to improve fill pattern
- Confirm that the part ejects uniformly
- Check for proper handling and immediate degating of parts after ejection
- Decrease mold temperature
- Increase post-cooling time
- Ensure that the part is properly packed by
  - Increasing the injection pressure, injection rate

6.4.14 Weld lines

- Eliminate mold release agent
- Increase injection rate
- Increase injection pressure
- Increase mold temperature
- Increase melt temperature
- Vent cavity in weld line area
- Provide overflow well adjacent to weld line area
- Use single gate
- Improve flow pattern by
  - Relocating gate
  - Ensuring wall thickness is uniform
  - Adjusting wall thickness variations to direct the melt flow

7. Extrusion

A number of unreinforced Vectra LCPs can be used for extrusion of rods, profiles, films, sheets, pipes and fibers. In addition, one grade of unreinforced Vectra permits coextrusion with standard packaging materials. This offers packaging producers a cost-effective way of exploiting the excellent gas barrier properties and chemical resistance of LCPs. As a result of their molecular structure, LCP extrudates generally have highly anisotropic properties. This can be improved by suitable processing techniques. For example, blown film technology can be utililzed to reduce the anisotropy of LCP films. Unfilled Vectra grades must normally be used for this purpose. With blown films up to about 100 µm thickness, similar physical properties in the machine and transverse directions can be obtained by adjusting the draw ratio in the machine direction and the blow-up ratio in the transverse direction. The tensile modulus can range between 20,000 MPa/3,500 MPa (in the machine direction/ transverse direction) for an anisotropic cast film to 7,000 MPa/7,000 MPa for a blown film. This capabil - ity could be important in, for example, the electronics industry, where precise dimensional characteristics, including low shrinkage and a controllable linear thermal expansion coefficient, are required.

Mineral and fiber reinforced Vectra grades can also be used for extrusion as long as the die cross section is large enough to accommodate the filler. Filled resins are recommended for thermoformed sheet and extruded products that are to be machined. Fillers can also improve thermal and wear characteristics.

Be sure to follow the drying procedures outlined in section 5.2 before processing Vectra.

7.1 Machine requirements

7.1.1 General

Vectra should be extruded with a relatively cool feed zone. A barrel L/D ratio of 24:1 to 30:1 is recommended to ensure complete and uniform melting of the polymer. A vacuum vented extruder barrel ishelpful in eliminating volatiles in the extrudate

7.1.2 Screw design

The melt viscosity of Vectra is highly dependent on shear stress. Therefore select a metering screw with deep flights in the feed zone and a uniform pitch. A compression ratio of 2:1 to 5:1 for a single stage screw or the first stage of a two-stage screw is preferred. For the second stage of a vented screw, the compression ratio should be 2:1 to 3:1. The length of the feed section and the metering section should be at least five times screw diameter with a gradual transition between them.

7.1.3 Screen pack

Since Vectra is often processed close to the melt temperature, efficient screen pack heaters and good insulation are essential to prevent polymer freeze-up. A fine-mesh screen (down to 100 mesh apertures/ inch2) can be used for filtering the extrudate without causing excessive pressure build up. A screen filter should not be used when extruding filled polymer.

7.1.4 Head and die

Standard dies are generally appropriate for Vectra extrusion but, particularly in coextrusion, the low viscosity of Vectra should be taken into account by designing narrow flow channels. Uniform temperature distribution over the entire head and die area must be ensured by a suitable temperature control system. The melt pressure should also be as uniform as possible, and the screen pack replaced when the pressure starts to increase significantly.

7.1.5 Melt pump

Because Vectra is a shear thinning material, it tends to flow back over the screw flights more than con-ventional polymers. This can result in reduced screw pumping efficiency at high extruder discharge pres-sure. A melt pump is therefore recommended for high extrusion rates or whenever a filter (cartridge or screen changer) is used. The melt pump should be placed directly downstream of the extruder.

7.2 Processing

Safety precautions and startup/shutdown procedures for extrusion are very similar to those outlined for injection molding in section 5.1. Drying and storage of material are described in section 5.2.

7.2.1 Film and sheet

Extrusion of film and sheet can be carried out with either unfilled or filled Vectra polymers. Thermo -forming oper-ations generally require a glass or mineral filled grade, which can be used to extrude thicker-gage sheet.

Film and sheet are often extruded close to the melting point so care should be taken to prevent polymer freeze-up in the screen pack and die, especially at startup. Thermally insulating these components is helpful. Extrusion temperatures can be carefully lowered from the recommended values for thicker sheet (greater than 0.25 mm) if necessary to maintain melt strength.

The distance from the die to the finishing roll nip should generally be kept as short as possible to avoid premature freezing of the molten extrudate. A draw-down ratio (ratio of the die gap to film thickness) of 2.0 is recom-mended for thin film (less than 0.25 mm), and a draw-down ratio of 1.1 to 1.2 should be used for thicker film and sheet.

Standard center feed dies can be used to extrude film and sheet. A large manifold is recommended to distrib-ute the melt evenly across the die. The die gap setting should be adjustable to help regulate the die pressure and achieve the desired drawdown ratio.

Film up to 0.25 mm thickness can be cast on a single roll or extruded onto a three-roll stack. Thicker sheet may require a straight through string up. Finishing rolls should be heated, if possible, to provide a con-trolled uniform cooling rate and to produce a high quality film surface. Since Vectra films neck in less at the edges that other plastics, the required width of the finishing rolls for a given die size may be greater than expected based on previous experience. Film less than 0.25 mm thick may be wound on a spool, while thicker film generally must be cut into lengths.

7.2.2 Profiles

Monofilament strands, rods and other profiles can be extruded from unfilled Vectra plastics, preferably Vectra A950. High molecular orientation developed during extrusion gives these products exceptional tensile strength and stiffness in the machine direction. Due to their high melt strength, both products can be extruded either horizontally or vertically. A die melt temperature of approximately 280°C to 285°C is suggested for Vectra A950. Keep the die pressure above 0.7 MPa to maintain a consistent, densely packed product.

Unlike many other engineering thermoplastics, Vectra products exhibit very little die swell or distortion upon exiting the die. With the proper die design, minimal drawdown is required to achieve high mechanical strength. A drawdown ratio of 4 to 7 (ratio of die orifice area to cross sectional area of extrudate)
is recommended for best results

The entry to the die orifice should be streamlined and free of stagnation points so that polymer does not hang up and degrade. Conical entry dies with a 30 to 70° cone entry angle are recommended for extrusion of circular cross sections. A die with no land length is preferred but a short land length is acceptable. Keep the die land length to no more than 4 times the orifice diameter. A longer length will cause excessive shear deformation and reduction of tensile properties. A conical die mandrel is generally used with its tip centered upstream from the orifice entry.

Cooling and sizing of the extruded profile depends on the cross sectional area. Air-cooling is adequate for thin strands up to 0.15 mm diameter. A sizing guide should be used for any diameter greater than 3 mm.

Larger diameters and shapes should generally be water-cooled. Water baths should be temperature controlled and held at 45°C for small diameter pro-files (for example, 2 mm diameter rod running at
30 m/minute line speed). A short (approximately one meter) bath length is generally sufficient. The distance between the die face and the water bath normally ranges from less than 1 meter to 3 meters and may be adjusted to achieve the most circular cross section possible for the extruded monofilament.

Due to the stiffness of the extrudate, there should be no sharp bends in the line. Roll and take up spool diameters should be no less than 200 times the dia -meter of the extruded rod.

7.2.3 Pipe and tubing

A wide range of pipe and tubing diameters and thick-nesses can be extruded using Vectra LCPs. A melt pump between the extruder and the die provides a smoother, uniform extrudate and minimizes surging. It is recommended that extrusion melt temperatures be as low as possible to improve melt strength and increase production rates.

Small diameter tubes (up to about 2 mm) can be extruded directly into a cooling trough, while sizing is required for larger diameters. Where uniform con-trol of diameter and roundness are critical, a vacuum water-sizing bath is preferred. If a spider die design is used, the legs should be as far from the die outlet as possible to allow a molten extrudate to rejoin and form a homogenous melt. The spider should be care-fully centered to maintain a uniform wall thickness. A die land length of two or more times the tube dia -meter is ideal. Sizing rings may be used to control outside diameter uniformity and smooth the outside surface of the pipe or tube.

Sizing rings should be about 0.25 mm greater in diameter than the product. A protruding mandrel is required for effective sizing of the inside tube dia -meter.

A drawdown ratio (the ratio of the die flow annulus divided by the cross sectional area of the extruded tube) of 1.2 to 2.0 is recommended for tubing.

7.2.4 Coating

Vectra A950 is suitable for coating both conventional and fiber-optic cables. In fiber-optic cables, it protects and also strengthens the glass fibers. The coated pro -ducts have very low thermal conductivity, moisture and gas permeability, water absorption and thermal expansion.

Use a crosshead die with a converging nozzle for extrusion. A convergence ratio (ratio of the flow area cross section before and after convergence) of 10 to 20 is required to induce molecular orientation for good mechanical properties. The die land length should be about 6 mm or less to avoid excessive heat transfer to the glass fiber buffer coating.

The cooling water trough should be maintained at between 25°C and 45°C to prevent over-rapid cooling of the coated fiber. Keep a distance of 15 to 20 cm between the die face and the cooling water. Rolls need to be placed so that the coated fiber is never bent around a radius less than 100 times the coated fiber diameter.

The coated fiber can be further oriented by draw-down after exiting the die, which helps increase ten-sile properties. The recommended drawdown ratio is defined as:

$$\text{Drawdown ratio} = (A2-B2)/(C2-D2)$$

A = outside diameter of the die nozzle flow annulus
B = inside diameter of the die nozzle flow annulus
C = diameter of the coated product
D = diameter of the wire or fiber

7.3 Troubleshooting

As with the injection molding troubleshooting guide (section 6.4), many processing problems are caused by easily corrected conditions, such as inadequate resin drying, incorrect temperatures, etc. Try the recommended solutions given below in the order in which they are listed under each problem category.

7.3.1 General extrusion

Extrudate cross section varies with time

- Check line speed uniformity
- Check for extruder surging; reduce feed zone tempera ture to restore even flow
- Excessive drawdown; adjust die dimensions
- Install melt pump to stabilize flow rate

Extrudate has excessive voids

- If gassing appears to be a problem, reduce melt temperature or use vacuum vented extruder
- If melt pressure is less than 0.7 MPa, increase screw rpm, adjust die size, or use finer filter in screen pack (for unfilled plastics) to increase melt pressure

Poor surface appearance

- Dry plastic more thoroughly
- If gassing appears to be a problem, reduce melt temperature or use vacuum vented extruder
- If striations occur, raise melt temperature in 2°C to 3°C increments

Striations on extrudate in machine direction

- Check die for nicks
- Check all equipment surfaces for contamination or degraded resin

7.3.2 Pipe and tubing

Bowing of pipe or tubing

- Uneven cooling; make sure extrudate is completely submerged in cooling water
- Check for wall thickness variation
- Check alignment of extrusion and sizing dies

Poor surface only on inner wall

- Check for material buildup on die mandrel
- Adjust length of mandrel

Wall thickness variation

- Center the die mandrel

7.3.3 Profiles

Extrudate has distorted cross section

- Adjust melt temperature either higher or lower
- Adjust die to water bath distance
- Adjust drawdown ratio
- Sizing may be required

Strand breaks in extrudate

- Dry resin more thoroughly
- Raise melt temperature incrementally 7
- Reduce drawdown ratio if there is a periodic variation in cross section

7.3.4 Film and sheet

Large, uniformly spaced perforations in film

- Reduce melt temperature
- Decrease die gap to reduce drawdown
- Reduce die temperature

Sagging extrudate

– Lower melt temperature

Uneven or distorted edges

– Polymer freezes up on die edges; clean die and raise melt temperature

7.3.5 Coating

Breaks in optical fiber

- Make sure polymer and optical fiber are thoroughly dried
- Check for contamination in fiber guide
- Adjust tension at the unwind stand and die entrance

Out of round cross section

- Reduce melt temperature
- Center die tip nozzle
- Adjust die to water bath distance
- Adjust water bath temperature

8. Design

In most cases, designers and molders choose Vectra for its excellent dimensional stability, mechanical proper- ties, very good flow in thin walls and wide processing window. Part design is the key considera- tion in optimizing both processing latitude and part perfmance. In general, all the standard recommenda- tions for good design of plastic parts are applicable when designing Vectra components. For instance, parts should be designed and molds constructed to provide smooth, uniform flow of the polymer melt. In addition, the part design must control the poly- mer's anisotropic properties – a fact that presents both opportunities and challenges. This is because, with Vectra,the direction of material flow in the mold influences the mechanical properties of the molded parts more than with other thermoplastics. There is therefore a close link between part design, perfor- mance and end use requirements.

8.1 Part design

8.1.1 Wall thickness

Of all the issues in plastic design, selecting the proper nominal wall thickness is probably the most impor- tant. Choosing the proper wall sections sometimes deter- mines the ultimate success or failure of a product. While an inadequate wall section can lead to poor perfor- mance or structural failure, a section that is too thick, even just in certain regions, can make the product unat- tractive, overweight or too expensive. Although some problems can be corrected after the mold is built, such solutions are often expensive.

The vast majority of injection molded plastic parts have wall thicknesses in the range of 1 mm to 5 mm. Because of the low viscosity and easy flow of Vectra, typical wall thicknesses are in the range of 0.3 mm to 1 mm. Thick- ness within this range is generally related to the part size. This does not mean that parts cannot be molded thinner or thicker, or that a large part can- not be thin or a small part thick.

However, these norms should act as a starting point for the design.

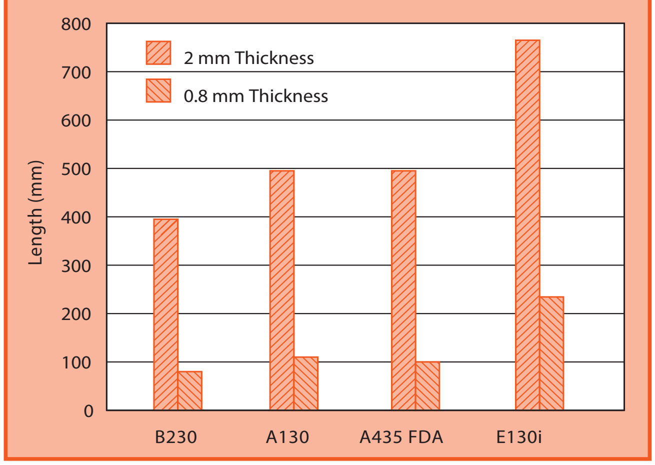
If a part is subjected to any significant loading, the load-bearing areas should be analyzed for stress and deflection. If the stress or deflection is too high, the following alternatives should be considered:

a) Use ribs or other suitable contours to increase the moment of inertia
b) Use a Vectra grade with higher strength
c) Increase the thickness of the wall section if it has not already reached the limit.

Plastic parts are good insulators for electrical and heat energy. They can also serve as filters for sound, vibra- tions and light. In general, insulating ability is directly related to the thickness of the plastic. In the case of sound transmission, the wall thickness of a plastic hous- ing may need to be changed to avoid the resonance frequency.

The impact resistance of a particular part is directly related to its ability to absorb mechanical energy without fracture or plastic deformation. This in turn depends on the properties of the plastic and the geome- try of the part. Increasing wall thickness gener- ally improves the impact resistance of the molded part. However, increased wall thickness could also negatively affect impact resistance by making the part overly stiff, unable to deflect and distribute the impact. Both types of impact energy absorption should be tested when deciding on nominal wall thickness.

Fig. 8.1.1 · Spiral Flow Lengths
(Injection pressure: 195 bar hydraulic/1000 bar specific, Mold temperature: 100°C)



7

8

8.1.2 Flow length

The spiral flow length values for the melt are determined in the spiral flow test, which very closely simulates actual injection molding conditions. In Fig. 9.1.1, the spiral flow lengths of selected Vectra grades under typical injection molding conditions are shown for two different wall thicknesses. The spiral flow lengths vary according to factors such as gate cross section, mold or melt temperature and, especially, injection rate. So the quoted values provide only a relative indication of the flow lengths that can be expected from the different polymers in the mold. In planning the design of a part, therefore, the information given in Section 8 Rheology should also be taken into consideration.

8.1.3 Shrinkage

The change in volume of Vectra on solidifying from the melt is considerably less than that of conventional thermoplastics on account of its liquid crystalline structure. Shrinkage of Vectra depends mainly on orientation and therefore on the flow paths in the mold determined by part design, wall thickness and gate location. Shrinkage in the flow direction can even be virtually zero (see enclosed product informa- tion and data sheets). Shrinkage anisotropy is greatest with unfilled polymers and – unlike with other ther- moplastics – can be reduced by the use of fillers. The effects of melt and mold temperature, injection pressure and injection rate on shrinkage are negligible relative to other engineering plastics.

Because of the low shrinkage, polished molds are recommended to avoid ejection problems. If necessary, a suitable draft (see section 8.1.4) should be provided to assist removal from the mold. The low shrinkage of Vectra coupled with its low coefficient of thermal expansion (section 3.2.3) offers the advantage of very high manufacturing precision and very close tolerances (tolerance class IT6). This makes it possible to achieve high reproducibility of the part dimensions, which can be a crucial advantage for automatic assembly of components leading to a considerable reduction in manufacturing costs.

8.1.4 Draft angle

Vectra LCPs exhibit very low shrinkage and unusually high stiffness. Consequently, they typically eject easily from most cores. If necessary, parts can be ejected from molds with well-polished cores without any draft. Even so, molding parts without a draft should be considered only when there are no alternate options. A draft angle of 0.1 to 0.25 degree per side is suggested. Larger draft angles provide easier ejection. Parts with undercuts cannot generally be ejected because of Vectra's high stiffness. However, slight undercuts or roughened surfaces can be used to assist adhesion to the desired mold half (= ejector half) and so help control ejection.

8.1.5 Warpage

Controlled, uniformly flowing melt fronts are crucial to preventing warpage. Wall sections should be as uniform as possible, since parts are subject to warping if there is, for example, a thick wall on one side and a thin one opposite. Warpage can be restricted to a minimum, if parts are designed so that the polymer melt can flow evenly and continuously in a longitudi- nal path from one end of the mold to the other with- out forming weld lines.

The difference between mold shrinkage in the flow and transverse directions is roughly comparable to that for other 30% glass fiber reinforced semi-crys- talline plastics such as PBT. The differential shrinkage can be eliminated or greatly reduced by relocating the gate and by suitable design of the part. With com- plicated moldings, it is extremely difficult to predict shrinkage exactly since the flow behavior of the melt and subsequent orientation is difficult to foresee.

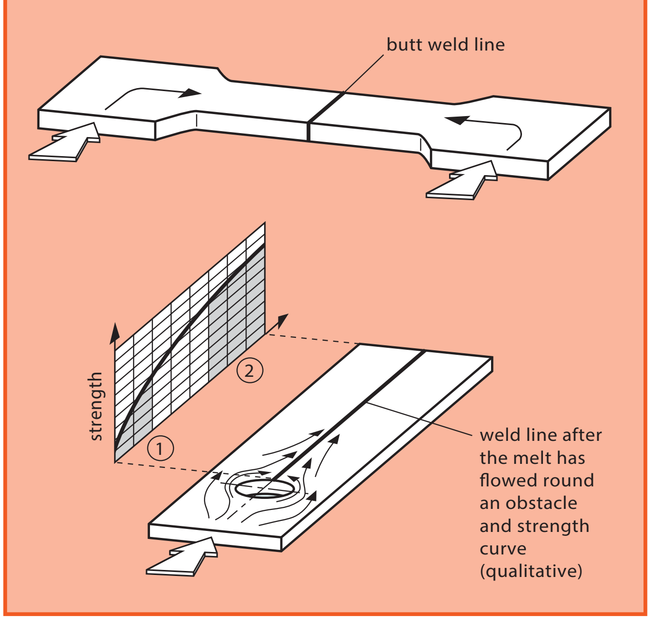
8.1.6 Weld lines

Weld lines are weak points in any molding made from reinforced plastics. In injection molding liquid crystal polymers, not only any fibrous reinforcing materials present but also the molecular chains them- selves are oriented largely parallel to the weld line. The reinforcement is therefore interrupted in the region of the weld line. Hence, great attention must be given to the weld lines.

Butt welds, in which the melt fronts meet and remain in a plane perpendicular to the flow direction, are often particularly critical (see Fig. 8.1.2 top). The strength of a test specimen produced in this way can be reduced by up to 90%. Such a weld line frequently also leads to a visible surface mark.

Moldings with weld lines formed after the melt has flowed around an obstacle (core) retain 50 to 60% of the transverse strength of parts without a weld line (see Figure 8.1.2 bottom). The melt stream is divided into two at the obstacle and when the two streams reunite, welding is impaired by the rapid cooling of the melt. When two melt streams meet directly behind the core at an obtuse angle, similarly low strength results as with a butt weld line. With growing dis- tance from the obstacle, the two melt streams meet at an increasingly acute angle until a parallel flow front

Fig. 8.1.2 · Weld Lines



has formed. Strength increases correspondingly with increasing distance from the obstacle. Because of the higher melt temperature, weld lines that are formed at the beginning of the filling process are stronger than those at the end of the flow path. This factor should be taken into account in selecting the gate position.

A molding without weld lines has the highest design strength. If weld lines are unavoidable, they should be sited in regions of low stress through suitable location of the gate. If possible, butt welds should be avoided. Long weld lines after an obstacle are preferable to short weld lines. It has proved an advantage to create swiring in the weld line by providing a flow obstacle such as a rib or coring.

Another way to improve the strength of weld lines is to create an overflow well or tab. The melt can then flow from the end of the weld line into the overflow. The overflow is then trimmed off the molded part.

8.1.7 Ribs, corners, radii

The provision of ribs on molding walls is one possible means of increasing design strength and at the same time avoiding material accumulation due to excessive wall thickness. However, ribs influence melt flow in the mold and can cause undesirable weld lines or possibly warpage. If the flow direction of the melt coincides with the longitudinal axis of the ribs, the thickness of the ribs should be as near as possible to the thickness of the adjacent wall (80 to 100%).
The melt then flows in the same direction through the rib and wall. If the rib is thinner, there is a tendency for the melt to first rush through the wall and then flow in the transverse direction into the rib. This would set up different directions of orientation and lead to warpage. Any bosses should have the same wall thickness as the ribs.

Rib connections to adjacent walls should be radiused. Radii of 0.1 to 0.2 times the thickness of the adjacent wall are recommended to reduce notch effects. Larger radii cause the melt to rush into the rib connection possibly resulting in undesirable weld lines or "back filling" of the molded part.

Transitions, corners and molding edges should have generous radii, provided this does not result in dis- advantages for uniform mold filling (rushing of the melt, weld lines). For outside radii, 1.5 times the wall thickness is recommended; for inside radii 0.5 times wall thickness.

8.1.8 Holes and depressions

Holes and depressions or thinner areas are particularly critical design issues because of the need to carefully consider the impact of weld lines on the integrity of the molded Vectra part. Typically, to optimize the strength of a molded-in hole the minimum distance between the edge of the hole and the edge of the part should be at least twice the hole diameter or at least twice the nominal part wall thickness. Generally speaking, the greater the distance, the stronger the part. A weld line can be critical if a snap-fit or press- fit pin is to be inserted into the hole.The stress at the hole may cause a weak weld line to fail. Similar rules hold for depressions, since they can also cause a downstream weld line. The design situation is less critical, since there is generally no external stress imposed on a depression. If the part design is con- strained to smaller than recommended dimensions between the hole and edge of the part, the weld line may be strengthened by placing an asymmetrical “overflow” gate and well in the vicinity of the weld line. This can dramatically strengthen a weld line.

8.1.9 Snap-fits and press-fits

Snap-fit joints designed in Vectra should be tapered (typically a 2:1 taper) to provide a more uniform stress distribution along the length of the beam. This design technique will limit the stress concentration at the base of the snap-fit. Additional deflection can also be achieved using this tapered beam approach.

Press fits depend on the interference of the compo- nents to hold the assembly together. With low elon- gation, high modulus materials such as Vectra, if the strain is too high, the material will fracture, losing the retention force designed to hold the components together. Except for very light press fits, this type of assembly is not recom- mended due to the hoop stress in the boss, which might already be weakened by
a weld line. Designing an interference press fit by adding “crush ribs” to the inside diameter of the boss or hole is a technique that can lower the stress while maintaining retention. Other techniques such as the use of barbs or splines on metal pins that are inserted into the plastic can create interference and provide effective holding forces.

8.2 Mold design

The quality of a molded part is essentially determined by the following factors:

- Properties of the molding material
- Design of the molded part
- Processing of the material

By optimizing all these factors, a high quality molded part can be produced. The design of the mold and molded part are particularly important in processing LCP. Just the location and design of the gate have a significant influence on the achievable quality of the part. For this reason, close cooperation between the raw material manufacturer, designer, processor and customer right from the start of the project is very desirable.

Processing is determined both by the set injection molding parameters and the design of the machine and mold. Modern simulation methods are available to assist in the mechanical, thermal and rheological design of a mold.

It is often possible to assess whether a molded part will meet requirements, by applying the principles of materials science. Trials under closely simulated service conditions should be carried out to confirm practical suitability for the application.

8.2.1 Mold material

The selection of steels for the mold can be critical to its successful performance. Just as plastics are formu- lated to satisfy processing and performance require- ments, steels are alloyed to meet the specific needs for mold fabrication, processing and its intended use. There are many different parts to the mold, e.g. cavity, gates, vents, pins, cores, slides, etc., and these may have different requirements. For example, some applications may require a mold steel with high hard- ness to resist wear and abrasion at the parting line while another application may require toughness to resist mechanical fatigue. Usually, steels with higher hardness and wear resistance properties tend to be more brittle and steels with higher toughness will show less wear resistance. The selection process for the tool steels should include input from the tool steel supplier, the mold designer and mold fabricator in addition to the plastic supplier. Post-treatment of the mold can be used to reduce the propensity for wear. Inserts should be considered where wear may be a concern and long production runs are anticipated.

Table 8.2 lists some steels that could be considered for constructing injection molds.
To achieve satisfactory protection against wear, the recommended hardness should be at least Rc ≥ 56, especially for processing highly filled grades.

Recommended steels for Vectra LCPs are through hardening steels like S-7. As Vectra is not corrosive,

Table 8.2 • Partial Listing of Potential Mold Steels

Steel Type USA	Germany	Hardness	Properties	Typical Applications	Drawbacks
D-2	1.2379	60-62	Good hardness, good abrasion resistance	Gate inserts and cavity areas of high wear from glass and fillers	Brittle and somewhat difficult to grind and assemble
A-8		56-58	Good adhesive wear resistance, good toughness	Slides, lifters and cams	Fair abrasion resistance
A-6		56-58	Good heat treatment stability, high hardness and compressive strength	General purpose, air hardened steel	Moderate ductility
A-2	1.2363	56-58	Air hardened steel, high abrasion resistance and good toughness		Moderate ductility
S-7		54-56	Very good mechanical fatigue resistance and toughness		Fair adhesive and abrasive wear resistance
O-1	1.2510	56-58	General purpose oil hardening steel with moderate adhesive wear resistance	Small inserts and cores	Medium to low toughness
L-6		55-57	Very good toughness, oil hardening with good heat treatment stability		Medium hardness with medium to low wear resistance
P-5		55-57	Highly malleable	Hobbing steel	Case hardened. Low core hardness, low durability and heat treatment stability
P-6	55-57		Easily machined and welded		Low heat treatment stability with medium to low durability
P-20	1.2311	28-34	Pre-hardened steel, very tough, easy to machine	Large cavities	Subject to galling and high wear Low hardness
H-13	1.2344	46-48	Air or vacuum hardened steel with very high toughness		Low hardness
SS 420	1.2083	46-50	Very good chemical resistance		Low hardness, low mechanical fatigue strength, low thermal conductivity
Specialty Steels					
M-2		62-64	Extreme hardness, abrasive and adhesive wear resistance	Gate inserts, core pins, shut off and part lines	Difficult and costly to machine and grind
Böhler "M 340"		56	Corrosion resistant		
Böhler "K 190"		60-63	Corrosion resistant		
Böhler "M 390"		56-62	Corrosion resistant and highly dimensional stable		
Zapp CPM T420V		57	Corrosion resistant, highly dimensional stable and easily polishable		
Zapp CPM 3V		53-63	Corrosion resistant, highly dimensional stable and high toughness		
Zapp CPM 9V		55-67	Highly dimensional stable		Low corrosion resistance
WST "G25"		64-66	Corrosion resistant		
Elmax1		56-58	Highly wear and corrosion resistant		
Ferro-Titanit S[2]		66-70	Extremely high wear resistant and corrosion resistant		

[1] Trademark is registered by Bohler-Uddeholm Corp. *[2] Trademark is registered by Thyssen Krupp Stahlunion GmbH*

special corrosion-resistant steels are generally not required. If the melt is injected against a wall or core, this area will be subject to higher abrasion. In such areas, wear-resistant materials, such as hard metal alloys like D-2 or 1.2379, should be considered or suitable surface treatment carried out. The mold surface should be smooth and polished to improve surface properties and facilitate ejection. The molds can be heated with water or oil.

8.2.2 Mold finish

Mold finish plays an important role in determining the ease of processing as well as molded part appear- ance. Vectra exhibits such low shrinkage that even modest undercuts can cause poor ejection. Even EDM (Electrical Discharge Machine) or erosion marks can hold the part or imbalance the ejection stroke. There- fore, the mold should be suitably polished. Deep or poorly drafted pins, cores and cavities require special attention. Fine polish- ing should occur in the axis of ejection (draw polishing).

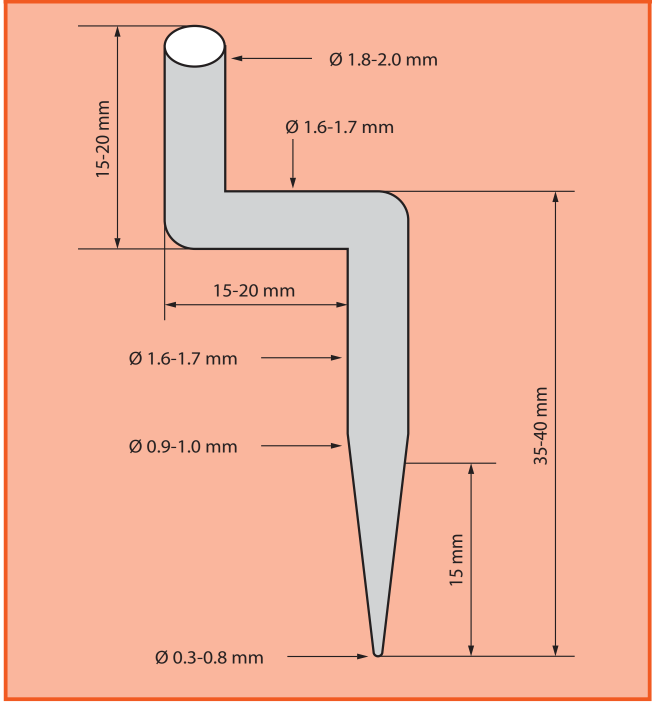
8.2.3 Runner systems

All typical runner systems (hot runner, conventional cold runner or hot-runner with cold sub-runner) can be used for injection molding of Vectra . Both full round and full radius trapezoidal runners are accept- able but full round runners are preferred. For multi- cavity tools, the runner system must be balanced and radiused carefully to avoid filling and ejection problems.

Hot runner systems have proven especially suitable for the production of small components because they avoid a situation where the sprue and runners account for an excessively high proportion of shot weight. There are now technically perfected hot run- ner systems for processing LCP. It is important to ensure that the amount of plastic in the hot runner is kept to a minimum. Since the residence time in the hot runner is additional to the residence time in the machine, the volume of the hot runner should not ex- ceed the equivalent of five shots. The total residence time (machine plus hot runner) must be limited to five up to a maximum of ten minutes.

When designing runner systems for Vectra, the high impact of shear forces on melt viscosity has to be taken into consideration. This applies to both hot and cold runner systems. To create optimum filling condi- tions, more shear has to be applied to Vectra than to other engineering plastics. Therefore, runners have to be generally smaller in diameter and should continu- ously increase shear. This is best achieved by suitably narrow- ing the runner cross section at each branch point. The reductions in flow rate that result from

Fig. 8.2.1 • Typical Runner Design for Vectra ® LCP



retaining the same runner diameter at branch points have a negative impact on shear, viscosity and orien- tation.

Due to the liquid crystal structure of Vectra, melting and processing conditions have a great influence on flow behavior and orientation. A typical Vectra run- ner design is shown in Figure 8.2.1.

8.2.4 Gate location

Selecting the gate location requires consideration of polymer orientation, warpage, jetting and weld line effects. As with all plastics, the gate location should be chosen as far as possible to achieve unrestricted and uniform mold filling. The gate location should control the cavity flow pattern to provide optimum mechanical properties in the axis of maximum stress. It should be noted that the viscosity of LCPs reacts very sensitively to pressure gradients. The material therefore always tries to fill moldings "from thick to thin", which can lead to uneven cavity filling if a gate is positioned at a point of low wall thickness. It is therefore advisable to position gates in the thickest part of the molding. However, gating directly into an open cavity can be problematic because it can lead to jetting. Jetting generally results in a weak point and so reduces the quality of the molded part. To avoid jetting, gates should be positioned so that the melt stream impacts directly on a rib, core or nearby wall.

Part shrinkage in the flow direction is smaller than in the transverse direction. The resultant shrinkage differential might cause warpage. When flatness is critical, locate the gate to minimize orientation (shrinkage) differences, i.e. balance them across the part or relocate them to non-critical areas. Due to the high flow of Vectra, single gates are generally suffi- cient. Avoiding multiple gates minimizes weld lines. When multiple gates are unavoid-able, locate the gate so that weld lines occur in areas with lower mecha- nical loads and minimal strain. Note that knit weld lines are significantly stronger than butt weld lines (Fig. 8.1.2). The gate should be located so that a knit weld line is formed as early as possible during the filling process to ensure good welding of the flow fronts.

Since these effects must be carefully balanced, it is important to check the filling pattern when proofing new or existing tools. Simply limit the shot size and inspect a series of short shots taken throughout cavity filling, i.e. from the moment the melt comes through the gate to the point of final fill. In making new tools, the gate area should be part of an insert to facilitate changes or adjust-ments.

8.2.5 Gate design

Jetting is a phenomenon that results when plastic flows through a gate and directly into a cavity with- out meet-ing an obstacle. It produces a rope-like melt flow or "jet" which, in the case of LCP, immediately freezes and is then surrounded by the subsequent melt flow. Ideally, immediately at the gate, the poly- mer should form a swelling flow stream with a uni- form flow front that fills the cavity evenly. Vectra has very little die swell when exiting the gate and is there- fore more prone to jetting than many other thermo- plastics.

With three-plate molds and submarine gates, a small- er gate is more practical for a cleaner break. Because of the increased flow rate of Vectra in comparison with other thermoplastics, particular care must be taken in this case to direct the flow against a core or cavity wall to prevent jetting and ensure that uniform flow develops. Vectra moldings are stronger in the flow direction and there-fore gates should be located on the ejector half of the mold to push rather than pull the sprues and runners from the mold. In three- plate molds, sprue diameters should be between 20% and 50% of the wall thickness to ensure that the sprue breaks off easily. The corre-sponding gate diam- eters should be between 0.3 and 0.8 mm. Experience with Vectra shows that narrower runners and gates reduce viscosity because of the increased shear and therefore enable the cavity to be filled more easily.

8.2.6 Gate types

As with gate location, it is important to select the gate type appropriate to the part geometry. Currently used gate types are described below. For Vectra, injection molders usually choose submarine gates.

8.2.6.1 Submarine (tunnel) gates

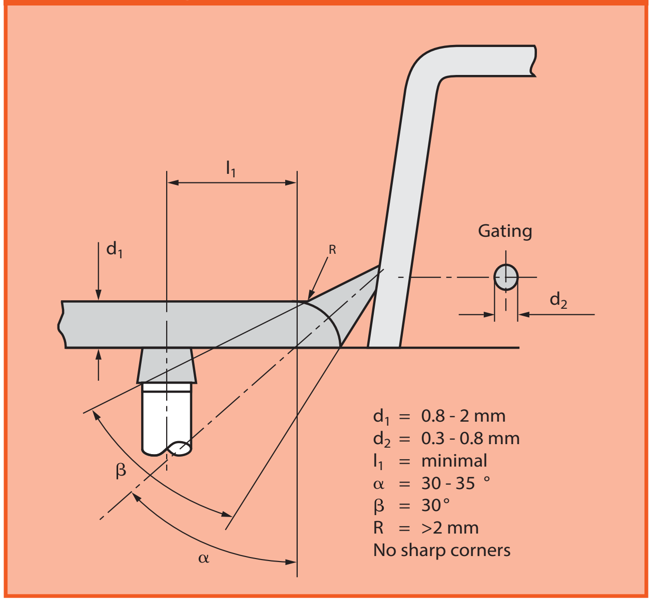
Submarine gates (Figure 8.2.2) require careful sizing to balance the ejection difficulties of large gates with jetting of small gates.

Furthermore, the drop from the runner must flex enough to clear the cutting edge as the tool opens. Vectra is very stiff, so the gate design must maximize flexibility and minimize the deflection required during ejection. The runner diameter should be small and the ejector placed close to the gate (see Fig. 8.2.2 length l1).

The converging angle of the cone should be relatively small (about 30°) and the drop angle from the runner relatively steep (about 60°). Most importantly, the submarine gate should extend into the ejector side of the tool so the ejection stroke can positively separate the runner from the part.

The ejectors should be robust and close to the gate because Vectra has very high tensile and shear strength in the highly oriented gate drop. If the sub- marine gate extends into the stationary side, the run- ner could split at the pullers rather than break at the gate.

Fig. 8.2.2 • Submarine Gate



8.2.6.2 Pin gates

Pin gates are used for thin-walled moldings and easy degating in most 3-plate tools. As with any small gate, direct the polymer flow onto a core, rib or cavity wall to control jetting. If this approach is impractical, enlarge the gate to minimize jetting.

8.2.6.3 Film (fan) gates

Film gates are recommended for flat parts. A suffi- ciently thick transverse runner in front of the film ensures that the melt is distributed evenly across the land before entering the cavity. This way a homo- geneous filling process is guaranteed, orientations are in line and warp- age minimized.

8.2.6.4 Ring and diaphragm gates

For cylindrical parts, a uniform flow front is critical to maintain concentricity, dimensional stability, part perfor- mance and appearance. A diaphragm or ring gate provides the best gate designs to obtain the uni- form flow front. In both types, the gate land or mem- brane should be significantly thinner in cross section (shallow- er) than the runner ring or central disk. This thickness differential forces the ring or disk to fill completely before the melt fills the membrane.

The choice of ring or diaphragm depends on part and tooling features. With an internal ring or diaphragm gate, the gate vestige is internal to the part. Depend- ing on the tool layout, the core may not seat as solidly as with an external ring. With an external ring gate, the core can be solidly seated but the gate vestige is external.

8.2.6.5 Overflow gates

A very effective technique for strengthening welds is to cut an overflow gate and well into the tool on the weld line. Changing the flat weld line plane into a three-di- mensional contour strengthens a normally very weak butt weld line considerably. This is done by first filling the mold in the normal way. Then during the packing step, a small amount of melt flows through the weld line plane into the overflow well. To create a successful overflow design, the mold must be completed, the part dimensions correct and the mold ready for final polishing. In other words, there must be no further changes in the metal contours.

The key to a successful design is to position the over- flow gate just slightly off the weld line and vent as deeply as possible. Weld lines are located on the part and the overflow gate can then be positioned about 1.5 to 2.5 nominal wall thicknesses away from the weld line location. A submarine or tab gate can be used; however, it must have a small enough area to ensure that flow only occurs after the part starts to pack out. This will ensure complete filling of the mold and proper formation of the weak weld line before the plane of the weld line is altered by the overflow. If the location is too near or too far from the weld line, there will be no flow through the weld line plane and so no strengthening of the weld line. A remov- able insert at the approximate location of the weld line can facilitate experimenting with the over- flow location to improve weld line strength.

8.2.7 Venting

The already low melt viscosity of Vectra is decreased significantly again with increasing injection rate. In addition, high injection rates can improve weld line strength. For this reason and to achieve fast cycles – Vectra is normally run at high injection rates so that the tool should generally be well vented. Since Vectra has extremely low melt viscosity, there must be a suf- ficient number of vents, which should if possible be polished and no larger than 0.025 mm. Vents in the runner system and parting line have proven particu- larly successful. Other vents should be located in sec- tions of the cavity where air could be trapped during filling, e.g. in the area of weld lines or bosses. Vents at several locations in the tool avoid forcing all of the air through one opening.

8.2.8 Ejection

Molded parts are generally ejected by ejector pins or ejector blades. These are round or rectangular shaped pins located in suitable areas of the mold for part ejection.The main purpose of the blade ejector is for the ejection of very slender parts, such as ribs and other projections, which cannot satisfactorily be ejected by standard types of ejector pins. The loca- tion and number of the ejector pin/blade elements are dependent on the component's size and shape. The mold should preferably be fitted with ejectors at weld lines and where shrinkage of the plastic is expected
(i.e. corners).

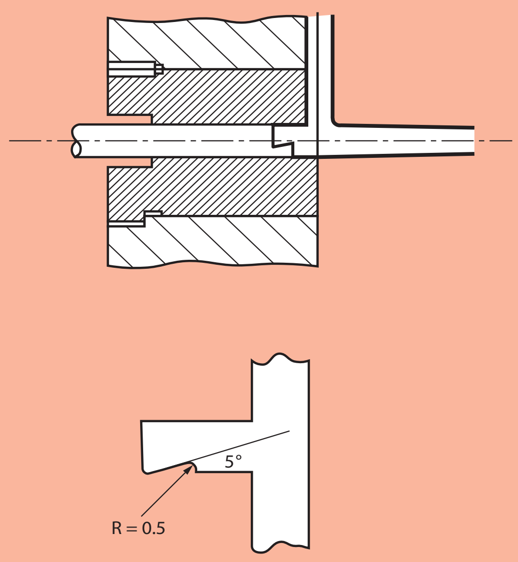
The ejector pins should be located so that the molded part is pushed off evenly from the core. Once the size of the ejector pins is decided, then the greater the number of ejector pins incorporated the greater will be the effec- tive ejection force and the less the likeli- hood of distor- tion occurring. For this reason it is bet- ter to err by having too many ejector pins than by having too few.

Experienced mold makers are usually able to predict knockout problems. Sometimes esthetic considera- tions or shortage of space prevent use of the required number of pins. It is poor practice to build a mold under these conditions. If a satisfactory ejection sys- tem cannot be designed initially on paper, it will be difficult, if not impossible, to instal it in the complet- ed mold.

Unless a molded part can be ejected consistently, an even cycle cannot be maintained and the part cannot be produced on a commercial basis.

Experience has shown that Z-shaped sprue pullers are very suitable for use in processing Vectra because of the material's unique characteristics. Figure 8.2.3 shows a diagram of a typical sprue puller used in pro- cessing Vectra.

Fig. 8.2.3 · Sprue Puller



9. Secondary operations

9.1 Annealing

The high heat deflection temperature of Vectra can be further raised 30 to 50°C by thermal aftertreatment (annealing) of the molded parts. This process can be carried out in air or nitrogen in a circulating air oven under the following conditions:

Vectra A series
- Heat oven from room temperature to 220°C over 2 hours
- Gradually increase temperature from 220 to 240°C over 1 hour
- Maintain at 240°C for 2 hours
- Gradually increase temperature from 240 to 250°C over 1 hour
- Maintain at 250°C for 2 hours
- Cool to room temperature

Vectra Ei series and Vectra S series
- Heat oven from room temperature to 220°C over 2 hours
- Gradually increase temperature from 220 to 250°C over 1 hour
- Maintain at 250°C for 2 hours
- Gradually increase temperature from 250 to 290°C over 1 hour
- Maintain at 290°C for 2 hours
- Cool to room temperature

During annealing, some color change may occur. This has no adverse effect on quality.

9.2 Assembly

The assembly and surface treatment of parts made from Vectra is quite similar to the methods used for conventional semi-crystalline plastics like nylon and polyesters. A factor that must be considered in designing joints and fastening techniques is the rela- tively weak weld line strength of liquid crystal poly- mer materials. Any joint produced by fusing parts together must have some shearing deformation over a large enough area to form a strong joint. When using any fastener that causes a high stress on the weld line either during assembly or service, the strength of the weld lines must be considered. Although Vectra LCPs have good chemical resistance, they can be successfully joined with adhesives, both with and without surface treatment. As with all injection molded parts, Vectra machined prototypes are poor imitations of the actual part, because most of the characteristics of Vectra are developed by flow during the injection molding process.

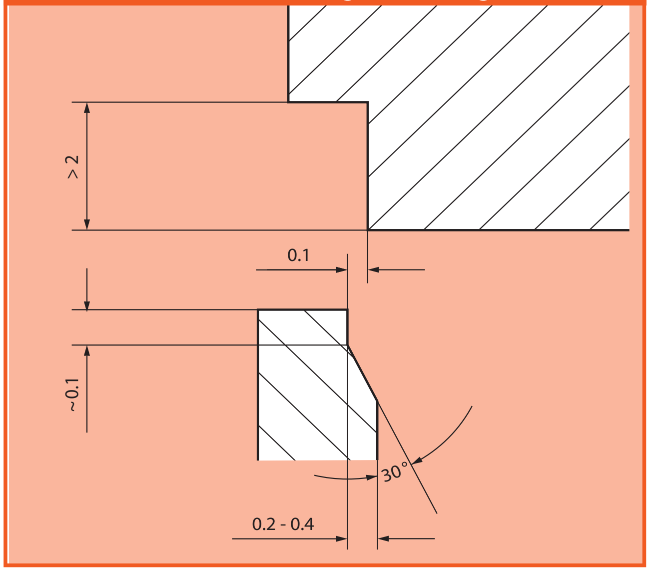
9.2.1 Welding

With the current trend towards rationalization and integration of plastic components, joining technology is becoming increasingly important. For production and assembly reasons, it is often an advantage to join molded parts after manufacture.

9.2.1.1 Ultrasonic welding

The most important requirement in ultrasonic welding of Vectra parts is to create an adequate pinch-off weld. In ultrasonic welding of Vectra, the joint strength depends largely on the shear length – a lon- ger shear length yields higher strength. Other types of joint design, such as the use of energy directors, result in low strength. The pinch-off weld should be designed in a conventional manner for a high modulus material, that is with about a 0.2 to 0.4 mm inter- ference and a greater than 2 mm depth (Fig. 9.2.1). The strength of the welded joint will be determined more by the depth of the joint than by the inter- ference.

Fig. 9.2.1
Ultrasonic Welding Joint Design

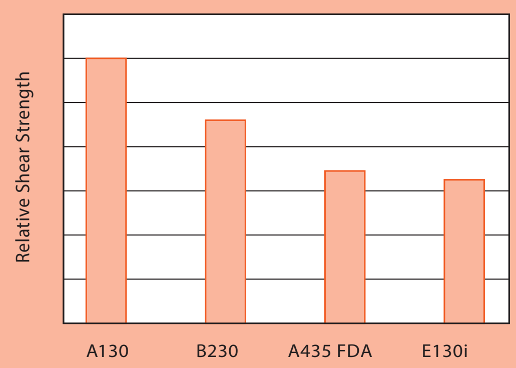


8
9

All high-melting-point plastics require high energy inputs to weld and Vectra is no exception. For most welding applications, a 20 kHz machine should be adequate. For very small parts (less than 13 to 19 mm diameter), a 40 kHz machine should be considered. Horn amplitudes will generally be between 0.05 and 0.08 mm for 20 kHz frequency and about half that for 40 kHz .

The expected weld strength will depend on both the actual welding conditions and the grade of Vectra used. Joint shear strength of about 30% to 50% of the bulk material strength should be expected when the above guidelines are followed. Fig. 9.2.2 shows the relative weld strengths for various Vectra grades.

Fig. 9.2.2 • Ultrasonic Weld Strengths



During ultrasonic welding tests, horn wear was observed. This can be avoided by using a hard metal material or a polyethylene film layer as a buffer. Owing to the stiffness of Vectra, the ultrasonic welding process can be noisy. A silicon rubber layer underneath the parts helps diminish the noise.

9.2.1.2 Rotational (spin) welding

Joint design is critical for maximizing weld line strength. With the optimum design (Fig. 9.2.3), weld strength up to 50% of bulk material strength can be achieved. Owing to the compressive behavior, it is difficult to establish the most suitable jointing area in the part. Fig. 9.2.4 gives representative values for weld strength as a function of design.

Fig. 9.2.3
Spin Welding Joint Design

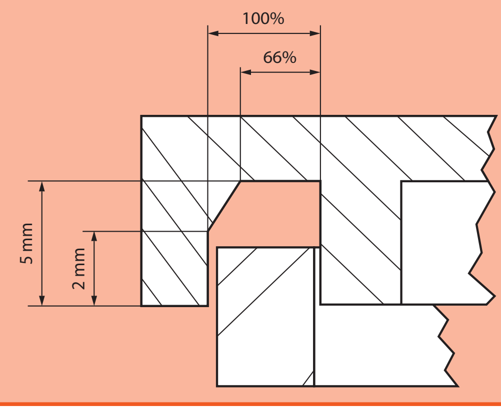
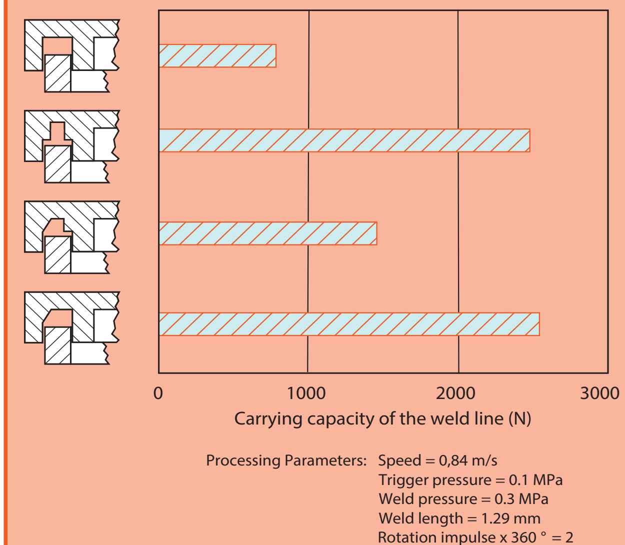


Fig. 9.2.4
Spin Weld Strengths for Vectra® A130



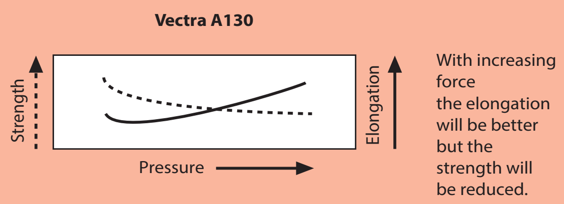
9.2.1.3 Hot plate welding

Hot plate welding is not recommended for Vectra moldings. The strength of the weld is 12-15% of the bulk material strength. There is no significant differ- ence between the values in the flow and transverse directions. The part should not have direct contact with the hot plate due to the tendency of Vectra to bond onto the plate. Radiant heat transfer alone sup- plies enough heat energy for the process.

9.2.1.4 Vibration welding

With vibration welding, the specific polymer structure of Vectra causes either long welding times with low pressure or short welding times with high pressure (Fig. 9.2.5). Low welding pressure is recommended. With low welding pressure, a weld strength of about 16% of bulk material strength can be achieved. Welding parallel to the flow direction is not recom- mended.

Fig. 9.2.5 • Vibration Welding

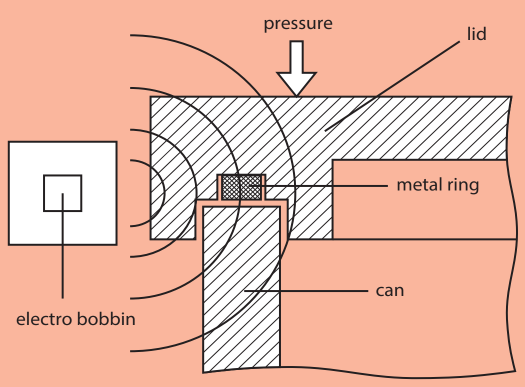


Processing Parameters: Frequency = 240 Hz
Amplitude = 1.4 mm
Weld pressure = <1 MPa
(for Vectra A130 Weld pressure = 3 MPa)

9.2.1.5 Electromagnetic welding

Electromagnetic welding is suitable for Vectra. The weld- ing quality depends on process parameters, which have to be defined together with the equip- ment manufacturer. For efficiency reasons, the longer welding times can be offset by use of a multiple welding system. During welding trials (Fig. 9.2.6), parts made from Vectra A130 and Vectra A625 withstood a breaking load of 1300 to 1650 newtons (Table 9.2.1).

Fig. 9.2.6 • Electromagnetic Welding



Processing Parameters:

Testing model:	can and lid with diameter = 30 mm and thickness = 3 mm
Cross section of ring:	2,25 mm (Steel C45)
Welding equipment:	KVT, Type 010 Generator UTG 20/3000
Welding time:	45 sec
Holding time:	20 sec
Power of generator:	2700 Watt (scale 90%)

Table 9.2.1 • Electromagnetic Welding Strengths

Variant	Pressure (bar) Trigger	Pressure (bar) Welding	Depth (mm)	Gastight 10 min./2.5 bar	Load to break (N)
Vectra A130	0.5	1.0	3.2 – 3.4	Yes	1664 ± 57
	1.0	2.0	3.4 – 3.5	Yes	1542 ± 162
	1.0	3.0	3.4 – 3.5	Yes	1550 ± 119
Vectra A625	0.5	1.0	2.3 – 2.6	Yes	1302 ± 288
	1.0	2.0	2.8 – 3.2	Yes	1752 ± 445
	1.0	3.0	3.2 – 3.3	Yes	1665 ± 108

9.2.2 Hot stamping

Hot stamping is the preferred way to form a "head" on a boss or rivet made from Vectra. Typically, a very hard surface is recommended for the shaping tool to reduce wear when heading bosses in parts molded from the frequently used glass fiber reinforced Vectra grades. Heating rates and temperatures are similar to those used with other semi-crystalline or amorphous thermoplastics like polyesters, nylons and polycarbo- nates. Dwell times, temperatures, pressures and cycle times should be estab- lished experimentally on molded prototype parts to make sure the parameters for a robust production process are known.

9.2.3 Adhesive bonding

Parts made from Vectra can be effectively bonded using readily available commercial adhesives. In most cases, the bond strengths obtained with unmodified surfaces are more than adequate for product assembly. Adhesive bond strengths can be further enhanced by surface treat- ments which improve wetting, such as plasma treatment, corona treatment, light sanding, grit blasting, and chemi- cal etching.

Table 9.2.2 · Lap Shear Strength

a) Testing Performed at 22°C

Adhesive Type	Range of Values, N/mm^2		Average Values, N/mm^2	
	As Molded	Surface Treated*	As Molded	Surface Treated*
2 Part Epoxy	3.1 – 6.9	5.5 – 14.5	4.8	9.0
1 Part Epoxy	4.1 – 9.0	5.5 – 9.7	6.2	10.7
Cyanoacrylate	2.1 – 4.8	3.4 – 6.9	3.4	5.5
2 Part Acrylate	1.7 – 5.5	3.4 – 5.5	3.1	4.8

b) Testing Performed at 100°C

Adhesive Type	Range of Values, N/mm^2		Average Values, N/mm^2	
	As Molded	Surface Treated*	As Molded	Surface Treated*
2 Part Epoxy	1.0 – 2.1	1.0 – 2.8	1.4	2.1
1 Part Epoxy	1.4 – 4.8	1.7 – 5.5	3.4	4.1
Cyanoacrylate	2.1	2.1 – 3.4	2.1	2.8
2 Part Acrylic	0.7 – 1.4	1.4 – 2.1	1.0	1.7

c) Testing Performed at 150°C

Adhesive Type	Range of Values, N/mm^2		Average Values, N/mm^2	
	As Molded	Surface Treated*	As Molded	Surface Treated*
2 Part Epoxy	0.7 – 1.4	0.7 – 1.4	0.7	1.0
1 Part Epoxy	0.7 – 2.1	0.7 – 2.1	1.4	1.4
Cyanoacrylate	0.2 – 0.3	0.3 – 0.7	0.2	0.7
2 Part Acrylic	0.3	0.7	0.3	0.7

** Light sanding or grit blasting and solvent wash*

Most importantly, when bonding any molded plastic part, optimum adhesion will be obtained only when the parts are clean, the adhesive is fresh and the procedure supplied by the adhesive manufacturer is followed precisely. It is nearly impossible to com- pletely clean mold release from a molded part and mold release will prevent good adhesion. So, do not use mold release. Surfaces to be bonded should not be touched after cleaning, because an oil film may be deposited which could interfere with adhesion.

Certain Vectra grades provide greater bond strength than others. Generally, filled or reinforced grades of Vectra provide greater bond strengths than unfilled grades. Table 9.2.2 a, b and c shows typical shear strengths (ASTM D 3163) obtained with a variety of adhesives tested at 22°C, 100°C and 150°C, respec- tively. Before specifying these or any other adhesives, the end user should make certain that all mechanical, thermal, electrical, chemical and other properties of the adhesive are suitable for the application in question. Please note, these data are a general screening of classes of adhesives, not a specific recommendation. Table 9.2.3 presents commercial examples of the adhesives represented in Table 9.2.2. Table 9.2.4 includes examples of adhesives that comply with either FDA regulations or United States Pharma- copeia (USP) Class VI requirements.

Adhesion will be improved by proper surface preparation. Gas plasma technology has been successfully used to improve the adhesive bond strength between Vectra and epoxy and urethane adhesives. Table 9.2.5 shows the effectiveness of plasma treatment.

9.2.4 Fasteners

9.2.4.1 Screws

Vectra can be used for producing parts that will be joined together by screw fastening. Trials were con- ducted to develop the design and determine the best

Table 9.2.3 • Typical Adhesives for Vectra® LCP

Supplier	Grade	Family	Cure	Temp Range (°C)
Lord Corporation	Fusor® 310	2 Part Epoxy	15 minutes at 105°C	-40 to 205
3M Adhesives	Scotch-Weld® 1838 A/B	2 Part Epoxy	30 min at 95°C	-55 to 175
Cole-Parmer Co.	5- Minute Epoxy	2 Part Epoxy	1 hour at 20°C	-30 to 95
3M Adhesives	Scotch-Weld® 2214 Hi-Temp	1 Part Epoxy	10 minutes at 150°C	-55 to 175
3M Adhesives	Scotch-Weld® 2214 Hi-Temp, New Formula	1 Part Epoxy	15 minutes at 150°C	-55 to 230
Epoxy Technology, Inc.	EPO-TEK® H35-175MP (Electrically Conductive)	1 Part Epoxy	1.5 hours at 175°C	-50 to 160
Delo Industrie Klebstoffe	Monopox 6093 Duopox AD 895	1 Part Epoxy 2 Part Epoxy	1 hour at 100°C 30 minutes at 80°C	-40 to 240 -40 to 180
Permabond International	Permabond® 102 [2)]	1 Part Cyanoacrylate	30 seconds at 23°C	-60 to 80
Permabond International	610/612 [2)]	2 Part Epoxy	25 seconds at 23°C	-80 to 150

1) REN is the registered trademark of REN Plastics Co.
2) Permabond is the registered trademark of National Starch an Chemical Corp.

Table 9.2.4 • Adhesives Compliant with US Regulations

Supplier	Grade	Family	Cure	Temp Range (°C)	In Compliance
Tra-Con	Tra-Bond FDA-8	2 Part Epoxy	4 hours at 65°C	-51 to 150	FDA*
Epoxy Technology	Epo-Tek 301	2 Part Epoxy	1 hour at 65°C		USP Class VI
Loctite	Medical Adhesive 4013	Cyanoacrylate	30 seconds at 20°C	-40 to 105	USP Class VI

** In compliance with FDA Title 21, US Code of Federal Regulations, Food and Drug Administration (FDA) Chapter 1, Sub Part B, Sections 175.105 and 175.300.*

Table 9.2.5 • Lap Shear Strengths

	Vectra A130		Vectra A625	
	Epoxy	Urethan	Epoxy	Urethan
No treatment	7.2 MPa	0.9 MPa	6.5 MPa	1.3 MPa
Oxygen plasma	11.4 MPa	9.3 MPa	11.0 MPa	6.7 MPa
Ammonia plasma	8.8 MPa	10.5 MPa	8.6 MPa	7.2 MPa

Table 9.2.6 • Typical Boss Dimensions

Material	Screw-type (EJOT)	Hole Diameter d	Boss Diameter D	Screwing Depth t
Vectra A130	PT	0.84 x d	1.90 x d	1.80 x d
Vectra E130i	PT	0.86 x d	1.90 x d	1.80 x d
Vectra B230	PT	0.90 x d	2.00 x d	1.90 x d

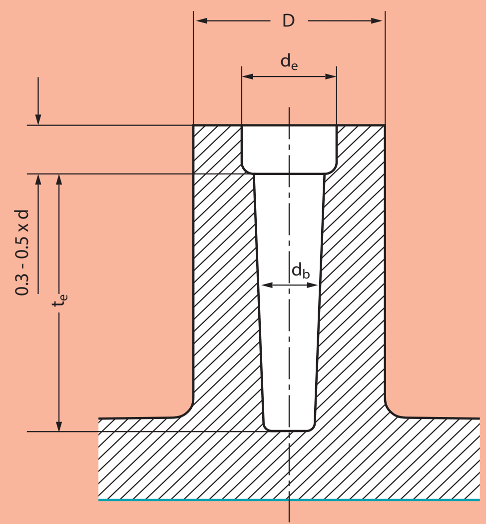
ratio of screw to hole dimensions. The screw hole diameter must be designed with very narrow tolerances. Table 9.2.6 gives typical dimensions for a screw.

Figure 9.2.7 shows a diagram of a screw hole boss. Design recommendations and dimensions are given in Table 9.2.7.

9.2.4.2 Ultrasonic inserts

Brass inserts are used to provide metal threads in thermoplastics. The inserts are installed using ultra- sonic or heat equipment that develops heat between the insert and the plastic. The heat remelts the narrow zone around the insert which, once resolidified, provides a high strength anchorage for the insert. The Ultrasert II insert from Heli-Coil has stepped inclined ribs that continually present new metal

Fig. 9.2.7
Boss for EJOT PT® K Screw



d = nominal screw diameter
D = boss diameter = 2 x d
d_e = d + 0.2 mm
t_e = screw depth
d_b = screw note diameter

surfaces to the plastic, so forming a continuous zone of melting and solidifying during installation.

This creates a homogenous polymer structure around the insert. The Ultrasert II has a unique knurled flange, which provides positive downward compressive force to the molten plastic that assures complete filling of the grooves for torque resistance. Table 9.2.8 shows the performance of these inserts in Vectra moldings in relation to three important criteria.

Table 9.2.8 • Performance of Molded-in Inserts (Dodge Ultrasert II inserts*)

Thread Size	Part number	Tensile strength (N)	Rotational torque (Nm)	Jack-out (Nm)
#2-56	6035-02BR115	420.5	0.9	0.3
	6035-02BR188	987.9	1.1	0.4
#4-40	6035-04BR135	842.4	2.8	1.0
	6035-04BR219	1764.4	2.9	1.7
#6-32	6035-06BR150	1067.1	3.2	0.8
	6035-06BR250	2182.2	3.4	1.9
#8-32	6035-2BR185	1359.5	3.8	2.0
	6035-2BR312	2247.3	5.7	2.9
#10-32	6041-3BR225	1659.0	6.3	3.7

**Emhart Heli-Coil, Shelter Rock Lane, Danbury, CT 06810*
Phone (203) 743-7651, Fax (203) 798-2540

Ultrasonic insertion conditions
(Branson Ultrasonic welder, model 8700)

Thread size	Booster	Weld time (s)	Hold time (s)	Air pressure (MPa)
#2	Black	0.4	0.5	0.10
#4	Black	0.5	0.5	0.10
#6	Black	0.6	0.5	0.14
#8	Black	0.6	0.5	0.14
#10	Black	0.7	1.0	0.14

Table 9.2.7 • EJOT PT® K Screw

	EJOT PT® K thread forming screw	nominal screw diameter, d (mm)	hole diameter, d_b (mm)	Penetration depth, t_e (mm)	driving torque (Nm)	stripping torque (Nm)	pull out strength (N)
Vectra A130	PT K 50 X 12	5	4.2	9.5	0.84	4.21	4170
	PT K 30 X 10	3	2.5	9.5	0.43	1.36	1640
Vectra E130i	PT K 50 X 12	5	4.4	9.5	0.54	2.38	2680
	PT K 30 X 10	3	2.5	6	0.37	1.09	1340
Vectra B230	PT K 50 X 12	5	4.4	9.5	0.79	2.6	3050
	PT K 30 X 10	3	2.7	6	0.4	1.09	

Supplier Information

Europe

DELO Industrie Klebstoffe
GmbH & Co. KG
Ohmstraße 3
D-86899 Landsberg
Tel: ++49 8191 3204-0
Fax: ++49 8191 3204-144

Poly Tec GmbH
Poly-Tec-Platz 1-7
D-76337 Waldbronn
Germany
Tel: ++49-7243-6040
Fax: ++49-7243-69944

3M Deutschland GmbH
Carl-Schurz-Straße 1
41453 Neuss
Germany
Tel: ++49-2131-140

Huntsman
Klybeckstrasse 200
CH-4057 Basel
Tel.: ++41-61966 4120

USA

Huntsman Advanced Materials
10003 Woodloch Forest Drive
The Woodlands, Texas 77380
Tel: ++1 (888)-564-9318

Cole-Parmer Co.
7425 North Oak Park Avenue
Chicago, IL 60648 USA
Tel: ++1 (847) 549-7600
Fax: ++1 (847) 247-2983

Epoxy Technology, Inc.
14 Fortune Drive Billerica,
MA 01821 USA
Tel: ++1 (800) 227-2201
Fax: ++1 (508) 667-4446

IPN
151 Essex Street
Haverhill, MA 01832, USA
Tel: ++1 (508) 372-2016
Fax: ++1 (508) 374-6955

Emerson & Cumming
Polymers
55 Hayden Avenue
Lexington, MA 02173 USA
Tel: ++1 (800) 832-4929
Fax: ++1 (617) 861-9590

Henkel Corporation
1001 Trout brook Crossing
Rocky Hill, CT 06067, USA
Tel: ++1 (860) 571-5100
Fax: ++1 (860) 571-5465

9.3 Decoration

9.3.1 Printing

Printing on untreated, freshly molded parts made from Vectra has been successfully demonstrated using one- and two-component inks. Pretreatment such as corona or plasma surface treatment may not be necessary. Ink suppliers are willing to assist with the selection of appropriate inks to match a customer's specific application. In most cases, they have the experience to guide the customer through the com- plete process. If necessary, they can modify the inks and even test trial parts.

Markem Corporation
150 Congress Street
Keene, New Hampshire 03431, USA
Tel.: ++1 (603) 352-1130
Fax: ++1 (603) 357 1835

Colorcon
A Division of Berwind Pharmaceutical
415 Moyer Boulevard
West Point, Pennsylvania 19486-0024, USA
Tel.: ++1 (215) 699-7733
Fax: ++1 (215) 661 2605

Tampoprint International Corp.
1400, 26th Street
Vero Beach, Florida 32960, USA
Tel.: ++1 (561) 772 8896
Fax. ++1 (561) 772 8289

Tampoprint AG
Lingwiesenstrasse 1
D-70825 Korntal-Münchingen
Germany
Tel.: ++49 (0) 7150-928-0
Fax: ++49 (0) 7150-928-400

9.3.2 Painting

Vectra LCPs can be painted but strict conditions must be observed. Because the plastic substrate is chemically inert, it is very difficult to improve the adhesion of paints to Vectra by chemical etching. Pretreatment with a primer is therefore recommended. Pretreatment with Ditzler polypropylene primer, code no. DPX801 has been used successfully in trials.

Ditzler/PPG Industries
One PPG Place
North Pittsburgh, Pennsylvania 15272, USA
Tel.: ++1 (412) 434-3131
Customer Service: ++1 (888) 774-1010

Schramm Coatings GmbH
Kettelerstrasse 100
Postfach 10 17 63
D-63017 Offenbach/Main, Germany
Tel.: ++49 (0) 69 8603-0
Fax: ++49 (0) 69 8603-229

Berlac AG
Allmendweg 39
CH-4450 Sissach, Switzerland
Tel.: ++41 (61) 976 9010
Fax: ++41 (61) 976 9620

9.3.3 Laser marking

Non-contact permanent marking of texts, patterns and serial codes on Vectra surfaces is possible using a laser beam. Two suitable laser-marking methods can be used:

– Nd:YAG laser
– Excimer or CO_2 laser

Laser marking conditions:

Energy – 18 amperes
Frequency – 5,000 Hz
Minimum writing size – 1 to 2 mm

Nd/YAG lasers produce anthracite-colored markings on natural Vectra surfaces and pale gray markings on black Vectra surfaces.

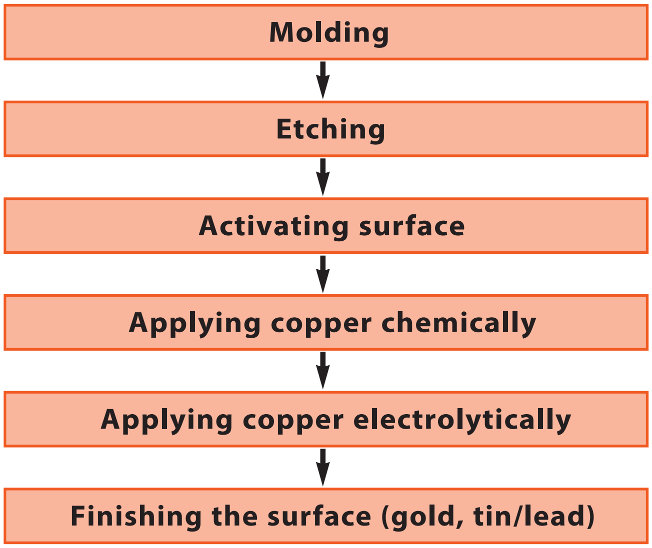
9.4 Plating and molded interconnect devices (MID)

9.4.1 Plating Vectra

In recent years, Vectra has increasingly been used for applications in which not only its characteristic properties but also suitability for plating are required.

The Vectra 800 series, for example Vectra E820i, has been specially developed for plating. These products allow micro-roughness to be generated on the surface of the part by an alkaline etching process, so that the metal layer is provided adequate facility for adhesion. Processing chemicals can be supplied by companies such as ROHM and HAAS, ENTHONE or ATOTECH.

The adhesive strength of the metal layer depends on the injection molding parameters (drying, injection rate, barrel temperature and mold temperature), the etching process and the test equipment. If the recommendations give here are followed, adhesion strengths from 0.9 to 1.5 N/mm2 can be achieved. The plating process is shown schematically below.



The chemically deposited layer of copper is generally 2 – 3 µm thick. The individual process parameters depend on the applications that have been developed by the various firms. After the etching and the depo- sition of copper over the whole surface, copper is then electrolytically applied until the desired layer thickness is achieved (approximately 20 – 30 µm). A barrier layer of nickel is then applied, and the surface is finished with tin/lead or with gold. Vectra E820i is suitable for the plating process described. Because of its special modification, Vectra E820i Pd does not require surface activation. This advantage makes it an excellent material for the production of 3D MID components (see MID).

In sputtering, the metal that is to be used to coat the component is subjected to ion bombardment to release ionized atoms into a surrounding vacuum. The atoms drift along the potential gradient from the metal source to the plastic part, where they accu- mulate in a hard, even layer. The thickness of that layer depends on the sputtering time. In practice, thicknesses of up to 5 µm are achieved with Vectra.

In aluminum vapor deposition, the components are placed in an evacuated chamber that also contains small aluminum blocks as the source of metal. Very high temperatures cause the aluminum to vaporize, and the aluminum cloud precipitates on the com- ponents. This method is used with Vectra to produce screening elements and reflectors, among other uses.

The addresses of some companies that have acquired knowledge of Vectra plating are included here:

In Europe:

FUBA Printed Circuits GmbH
Bahnhofstraße 3
D-37534 Gittelde/Harz
Germany
Tel.: ++49 (0) 5327- 880-0
Fax: ++49 (0) 5327- 880-200

Siegfried Schaal Metallveredlung GmbH & Co.
Laucherthaler Straße 30
D-72517 Sigmaringendorf
Germany
Tel.: ++49 (0) 7571-72 09-0
Fax: ++49 (0) 7571-72 09-23

Lüberg Elektronik GmbH & Co. KG
Hans-Striegel-Straße 3
D-92637 Weiden
Germany
Tel.: ++49 (0) 961-38159-30
Fax: ++49 (0) 961-62109

Collini-Flühmann AG
Ringstraße 9
CH-8600 Dübendorf
Switzerland
Tel.: ++41 (0) 44 824 11 11
Fax: ++41 (0) 44 824 11 12

AHC – Oberflächentechnik GmbH
Coswiger Straße 16
D-12681 Berlin
Germany
Tel.: ++49 (0) 30-549904-0
Fax: ++49 (0) 30-549904-20

Molded Circuits LTD
1142 Melton Road,
Syston Leicester LE7 2HA
UK
Tel.: ++44 (0) 116- 260 9841
Fax: ++44 (0) 116-269 8392

In the USA:

Molded Interconnect Devices LLC
250 Metro Park
Rochester, NY 14623, USA
Tel.: ++1 (716) 272-3100

Circuit-Wise
400 Sackett Point Road
North Haven, CT 06473, USA
Tel.: ++1 (203) 281-6511

Cybershield of Texas
308 Ellen Trout
Lufkin, TX 75904
Tel.: ++1 (936) 633-6387

Metal Surfaces
6060 Shull Street
Bell Gardens, CA 90201, USA
Tel.: ++1 (310) 517-9285
Fax: ++1 (310) 517-9265

Crown City Platers
4350 Temple City Blvd.
El Monte, CA 91731, USA
Tel.: ++1 (626) 444-9291

Providence Metallizing Company, Inc.
51 Fairlawn Avenue
Pawtucket, RI 02860-2591, USA
Tel: ++1 (401) 722-5300
Fax: ++1 (401) 724-3410

9.4.2 MID

The production of three-dimensional circuit boards or so-called MID technology (MID = molded inter- connect device) is one of the most important application areas for the metallization of Vectra. With the aid of MID technology, it is possible to manufacture 3D circuit structures with great freedom of design by in- jection molding. The special combination of properties offered by Vectra makes it well qualified to produce molded interconnect devices. The following processes can be used for the manufacture of MID components:

The PCK (printed circuit board Kollmorgen) process (2-component injection molding):

First of all a pre-molding is produced from the plat- able, catalytically modified Vectra grade E820i Pd. Then this first shot is overmolded with a non-platable Vectra grade (e.g. E130i). The component is then etched and the molding surface selectively plated. With Vectra 2-shot technology, wall thicknesses of 0.25 mm can be achieved for the conductor track width and spacing. This process enables considerable cost savings to be made through miniaturization of components, higher integration density of functional elements, reduction in the number of parts and a high degree of automation.

LPKF LDS® process:

The energy of a laser beam can also be used to produce three-dimensional circuit boards. In this process, the component is injection molded entirely from Vectra E840i LDS, a grade specially developed for laser direct structuring (LDS). The component is structured (activated) with a laser in the places where the conductor tracks are later to be created. Finally, the component is selectively plated. The advantage of this process is its great flexibility. If the layout of the conductor tracks has to be changed, it is only neces- sary to reprogram the laser. This is a patented process developed by the company LPKF (www.lpkf.de). With this technology, conductor track widths of 0.15 mm and spacing of 0.2 mm can be achieved.

9.5 Machining

Although the usual aim of an injection molding process is to produce plastic parts that are ready for use as soon as they have been ejected from the mold, there are times when machining is needed. The properties of molded parts produced from Vectra are largely determined by molecular orientation, which in turn is influenced by gate and mold design and injection molding conditions. In preparing test speci- mens by machining, special care is needed. A test specimen will not, of course, necessarily have the same orientation structure as the finished molding, which can lead to differences in mechanical, electrical or other properties. If possible, therefore, test specimens should be produced by injection molding rather than being milled from blocks. In the case of Vectra, the properties of the surface layer differ significantly from those of the core. Where preparation of test specimens by machining is the only option, the minimum possible surface material should be removed. Every intrusion in the surface destroys the sandwich like structure and therefore crucially weakens the component. If the component design includes integrally molded holes, drilling such holes in the prepa- ration of test specimens invalidates assessment of weld line effects in the end product.

There are exceptional cases in which machining can be necessary. Reasons for this may be to avoid complex mold configurations or weld lines in critical areas. The following practical rules should be borne in mind when machining Vectra:

- Use sharp tools
- Provide adequate cooling
- Allow enough chip clearance
- Support the work properly

Compared to other thermoplastics, the stiffness, thermal conductivity and low coefficient of friction of Vectra promotes good machinability. Vectra is a thermoplastic and so will melt if the machining operation generates too much frictional heat.

9.5.1 Tooling

Dull tools tend to scrape rather than cut, yielding a poor surface finish and generating excess frictional heat in the process. The best surface finishes are obtained with sharp tools, high speeds and slow feed rates. Both machining speed and the feed rate should be uniform and uninterrupted. Cooling allows higher cutting speeds. Vectra is resistant to all currently used cutting fluids.

In addition to having sharp cutting edges, there must be adequate clearance for chips. When there is a choice in tool selection, the machinist should pick one offering the greatest chip clearance, for example, drills with wide flute areas or saw blades with deep gullets. Unlike some plastics containing abrasive fillers such as minerals, glass or carbon fibers etc., Vectra can be machined with standard high speed stainless steel tools, although carbide tools prolong tooling life during extended production runs.

9.5.2 Turning

Vectra can be easily turned on a lathe. Tool bits must be sharp and should provide a rake angle of 5 to 15° with front and side clearance angles of 0 to 15°. A tip radius of at least 1.5 mm should be used for smooth finish cuts. Feed rates and cutting speeds for turning depend primarily on the nature of the cut and the desired finish. For most work, a peripheral part speed of 0.3 m/s is reasonable. A smooth cut finish calls for a somewhat higher turning speed and slower feed rate. As a guideline, a 12 mm diameter rod turned with a 1.5 mm tool tip radius at 100 rpm and a 0.04 mm/ revolution feed advance delivers a good surface finish.

9.5.3 Milling and drilling

Standard helical-type milling cutters are suitable for Vectra. Two-flute end mills are preferred for greater chip clearance. Using the suggested tool speeds in Table 9.5.1, Vectra can be cut without a coolant. Feed rates should be adjusted to obtain the desired finish.

For drilling, standard high-speed twist drills are best. Occasionally burring may occur. This can be eliminated by clamping dummy pieces of plastic above and below the work. In any case, the work should be firmly supported and securely held. For deep holes, the drill should be raised frequently (about every 6 mm of depth) to clear the drill and hole of chips. A jet of compressed air helps to disperse chips and cool the drill.

Table 9.5.1 · Tool Speeds for Drilling or Milling

Tool diameter (mm)	Tool speed (rpm)	
	Unfilled grades	Reinforced grades
1.6	2,300	2,000
3.2	2,000	1,700
5.6	1,800	1,500
6.4	1,600	1,300
9.5	1,300	1,000
15.9	1,000	800

9.5.4 Threading and tapping

Threads may be readily cut on a lathe, using the tool and cutting conditions previously outlined. Conven- tional taps and dies may be used with good results. These may be threaded either by hand or by machine. A speed of about 180 rpm is suggested for screw sizes from UNC 10-24 through 3/8-16. The international metric equivalent sizes would be 6-1.00 to 10-1.50. A special tap for plastics, with two flutes, is available and offers some advantages in greater chip clearance but it is not essential for satisfactory results.

9.5.5 Sawing

Vectra may be sawn with almost any type of saw. To prevent binding of the blade, however, the saw teeth should have some degree of offset, at least 0.125 mm offset per side. Coarse teeth and extra wide gullets for chip clearance are desirable for rapid cutting, while a finer blade gives a smoother edge. In general, the blade should have at least two teeth in contact with the part at all times. Bandsawing gives a good finish cut without cooling, using a blade speed of approximately 17 m/s, when the part is less than 6 mm thick.

10. Conversion tables

10.1 Unit conversion factors

← Multiply by		→ Divide by
Length		
meter (m)	2.54×10^{-2}	inch (in)
meter (m)	3.05×10^{-1}	foot (ft)
Area		
square meter (m^2)	6.45×10^{-4}	square inch (in^2)
square meter (m^2)	9.29×10^{-2}	square feet (ft^2)
Volume		
cubic meter (m^3)	1.64×10^{-5}	cubic inch (in^3)
cubic meter (m^3)	2.83×10^{-2}	cubic feet (ft^3)
Mass		
kilogram (kg)	4.54×10^{-1}	pound (lb)
Force		
newton (N)	4.45	pound-force (lb_f)
newton (N)	9.81	kilogram-force (kg_f)
Pressure		
pascal (Pa)	=	newton/meter^2 (N/m^2)
pascal (Pa)	6.985×10^{-3}	lb_f/in^2 (psi)
mega Pascal (MPa)	6.985×10^{-3}	lb_f/in^2 (psi)
pascal (Pa)	9.807×10^{-4}	kg_f/cm^2
pascal (Pa)	10^5	bar
Viscosity		
pascal.sec. (Pa · s)	0.1	poise
Energy		
joule (J)	4.19	calorie (cal)
kilojoule/kilogram (kJ/kg)	4.19	calories/gram (cal/g)
joule/kilogram (J/kg)	2.33×10^3	BTU/lb
Technical textiles		
Linear mass density of filaments		
tex	9	denier
dtex	10^{-1}	mg/m
Tenacity		
cN/tex	1.132×10^{-1}	gf/denier

10.2 Stress conversion

Strength		Modulus	
MPa	psi	MPa	psi x 10^6
75	10 877	6 000	0.87
100	14 504	8 000	1.16
125	18 130	10 000	1.45
150	21 756	12 000	1.74
175	25 382	14 000	2.03
200	29 008	16 000	2.32
225	32 634	18 000	2.61
250	36 259	20 000	2.90
275	39 885	22 000	3.19
300	43 511	24 000	3.48

10.3 Length conversion

Inches	Inches	Mils	cm	mm
1	1	1000	2.54	25.4
1/2	0.5	500	1.27	12.7
1/4	0.25	250	0.64	6.4
1/8	0.125	125	0.32	3.2
1/16	0.0625	62.5	0.16	1.6
1/32	0.0313	31.3	0.08	0.8
1/64	0.0156	15.6	0.04	0.4

10.4 Temperature conversion

Degrees Celsius (°C)	Degrees Fahrenheit (°F)
0	32
10	50
20	68
50	122
75	167
100	212
125	257
150	302
175	347
200	392
225	437
250	482
275	527
300	572
325	617
350	662
375	707
400	752

Conversion factor °F = 1.8 · °C + 32

11. Subject index

Celanese

The chemistry inside innovation™

ENGINEERED MATERIALS

celanese.com/engineered-materials

Engineered Materials

- Celanex® thermoplastic polyester (PBT)
- Hostaform® and Celcon® acetal copolymer (POM)
- Celstran,® Compel® and Factor® long fiber reinforced thermoplastic (LFRT)
- Celstran® continuous fiber reinforced thermoplastic (CFR-TP)
- Fortron® polyphenylene sulfide (PPS)
- GUR® ultra-high molecular weight polyethylene (UHMW-PE)
- Impet® thermoplastic polyester (PET)
- Riteflex® thermoplastic polyester elastomer (TPC-ET)
- Thermx® polycyclohexylene-dimethylene terephthalate (PCT)
- Vandar® thermoplastic polyester alloy (PBT)
- Vectra® and Zenite® liquid crystal polymer (LCP)

Contact Information

Americas
8040 Dixie Highway, Florence, KY 41042 USA

Product Information Service
t: +1-800-833-4882 t: +1-859-372-3244

Customer Service
t: +1-800-526-4960 t: +1-859-372-3214
e: info-engineeredmaterials-am@celanese.com

Europe
Am Unisys-Park 1, 65843 Sulzbach, Germany

Product Information Service
t: +(00)-800-86427-531 t: +49-(0)-69-45009-1011
e: info-engineeredmaterials-eu@celanese.com

Asia
4560 Jinke Road, Zhang Jiang Hi Tech Park
Shanghai 201203 PRC

Customer Service
t: +86 21 3861 9266 f: +86 21 3861 9599
e: info-engineeredmaterials-asia@celanese.com

VC-7R3_LCP-020_VectraLCPDesignGuideBro_AM_0613